THE NATURAL HISTORY OF THE HAKE

PART III

SEASONAL CHANGES IN THE CONDITION OF THE HAKE

by

C. F. Hickling

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Seasonal Changes in the Condition of the Hake.

By

C. F. HICKLING, M.A.

Assistant Naturalist on the Staff of the Ministry of Agriculture and Fisheries.

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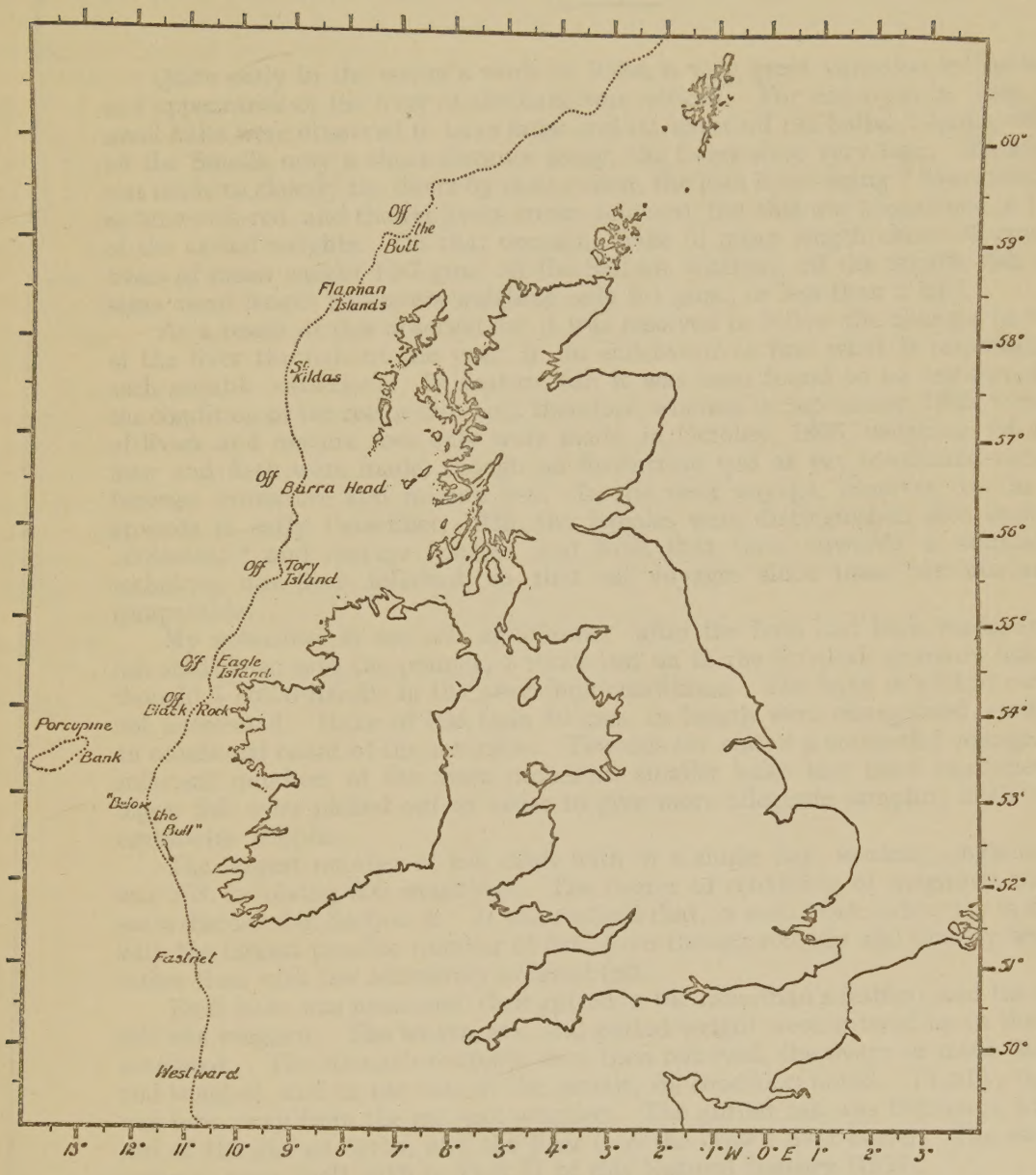
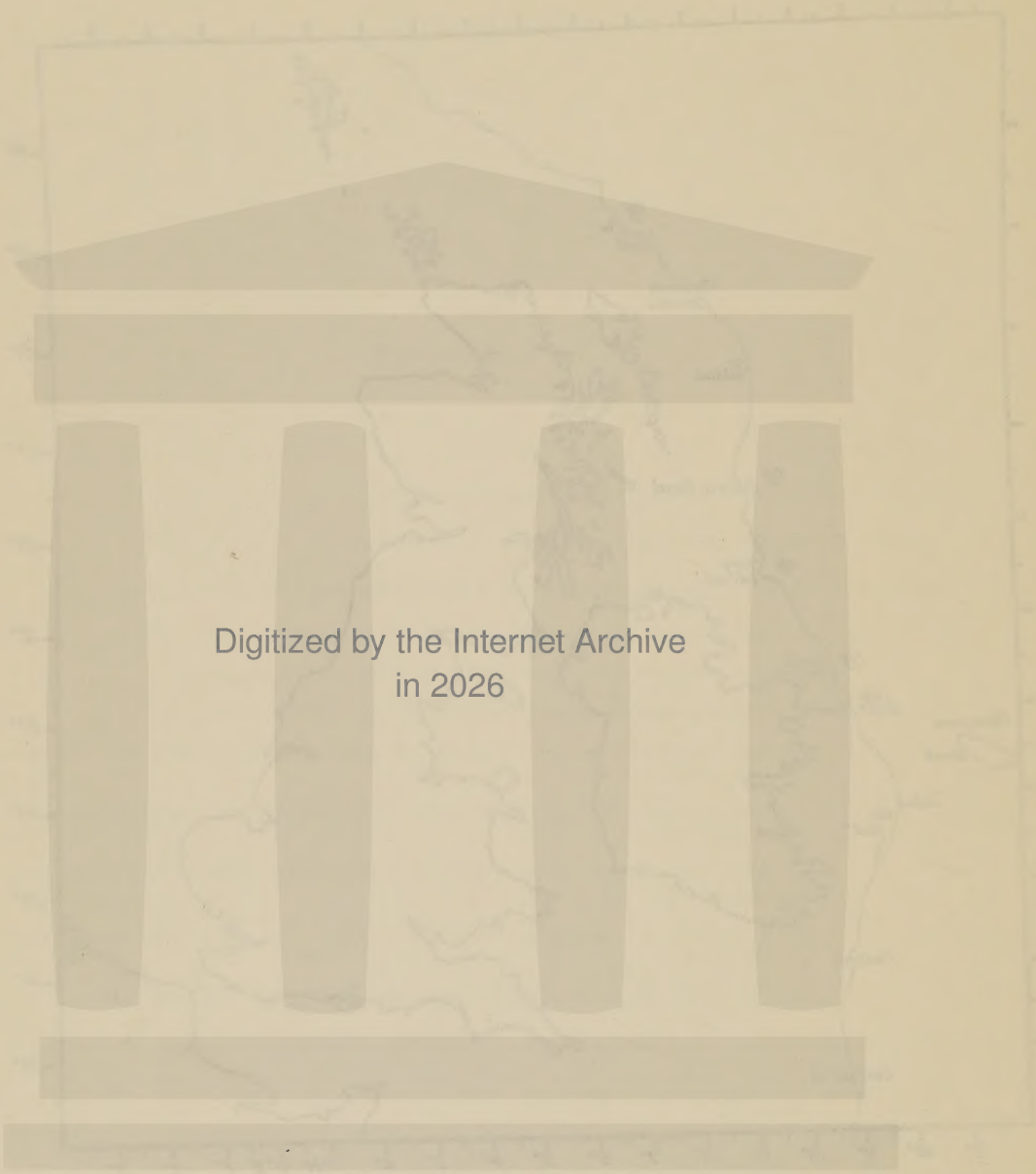


FRONTISPIECE.—The approximate localities and usual names of the chief deep-water hake fishing grounds. The 100-fathom contour is drawn.



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INTRODUCTION.

Quite early in the writer's work on hake, a very great variation in the weight and appearance of the liver of the hake was noticed. For example, in July, 1925, small hake were observed to have large and fat livers off the Saltee Islands, whereas off the Smalls, only a short distance away, the livers were very lean. An attempt was made to classify the livers by their colour, the lean livers being " liver-coloured " or brownish-red, and the fat livers cream-coloured, but this was abandoned in favour of the actual weights. On that occasion, hake of mean length about 35 cms. had livers of mean weight 19·7 gms. off the Saltees, whereas, off the Smalls, fish of the same mean length had livers weighing only 9·1 gms., or less than a half.

As a result of this observation, it was resolved to follow the changes in weight of the liver throughout the year, in an endeavour to find what is responsible for such notable variations. In mature fish it was soon found to be associated with the condition of the roe or milt and, therefore, whereas in September, 1925, weighings of livers and mature roes only were made, in October, 1925, weighings of gonad, liver and flesh were made, though no distinction was as yet considered necessary between immature and mature fish. In the next voyage, however, to the Bull grounds in early December, 1925, the females were distinguished into immature, adolescent,* and mature females, and from that time onwards a standardised technique has been followed, so that all voyages since these are intrinsically comparable.

My procedure at sea was as follows : after the haul had been made, and the fish shot down into the pounds, I threw out on to the foredeck as many hake as I thought I could handle in the prevailing conditions. The hake so picked out were not unselected. Hake of less than 50 cms. in length were disregarded, except for an occasional count of the sex-ratio. Towards the end of a successful voyage, when sufficient numbers of the more numerous smaller hake had been examined, the bigger fish were picked out, in order to give more adequate sampling in the higher centimetre lengths.

The largest number of fish dealt with in a single day, working single-handed, was 203, involving 609 weighings. The degree of reliability of weighings made at sea is discussed in Section A. It was realised that, in such work, safety lay in dealing with the largest possible number of fish, even though roughly and quickly weighed, rather than with few accurately weighed fish.

Each hake was measured, then gutted in the fisherman's fashion, and the gutted fish was weighed. The length, sex, and gutted weight were entered up in the rough note-book. The stomach-contents were then removed, the ovary or testis detached and weighed, and in the case of the female, its condition noted. Finally, the liver was torn away from the gut and weighed. The gutted fish was thrown in with the rest of the gutted catch, and the liver into the crew's liver-barrel. The stomach-contents were dealt with in Part II of this Natural History (1927).

Each hake, therefore, gave five or six items of information, namely, length, sex, condition of roe, weight of gonad, weight of liver, and weight of flesh. In this report, the gutted fish will be referred to throughout as the " flesh," in distinction from the liver and gonad.

The great bulk of the material has been obtained during voyages on commercial steam-trawlers, and may be accepted as representative of the larger fish in the hake shoals, at the time and region of observation, if it is granted that, by the method of " trial and error " (whether by the individual skipper, or by a whole fleet where

* *i.e.*, with the ovary approaching maturity, or attaining maturity for the first time.

there is wireless communication) the optimum depth has been found, so that one is sampling hake from the point and depth of greatest concentration of the shoals.

The collection of the data on commercial trawlers has often been both laborious and trying, but it has always been made a valuable and enjoyable experience by the unfailing hospitality, toleration and active help of skippers and crews in all conditions of luck and weather.

Most of the voyages were made on " Tamura," by courtesy of Messrs. Neale & West, of Cardiff, whose guest I was on these occasions. To them, and to Captain Drennan, my chief thanks are due. I am indebted to the same firm for a voyage on " Nogi," in January, 1928 ; to Messrs. J. Marr & Son, of Fleetwood, for voyages on " Alida " (November, 1925) and " Sir Mark Sykes " (January, 1926) ; to the New Docks S.T. Company for voyages on " Florence Brierley " (September, 1927) and " Kumu " (October, 1928) ; to the Kingston S.T. Company for a voyage on " Iolite " (June, 1928) ; and finally to M. Christaëns, of Boulogne, for a voyage on " Notre-Dame des Dunes " in April, 1928, arranged by M. Jean le Gall, of the Station Aquicole. To him and to M. Priol, who accompanied me to sea, my best thanks are due.

Since these lines were written, I have made a voyage (July, 1929) to the Firth of Clyde on the Swedish fish-cutter " Västerhavet," of Gothenburg. I have thus been able to examine hake from a fishery which cannot be prosecuted by British trawlers, and I am indebted to the crew of the " Västerhavet " for their hospitality and help, and to Messrs. J. Robinson & Co., of Fleetwood, for arranging the voyage. The results are included with those of the trawler voyages ; the hake were caught, however, with the Danish seine, in water varying from 21 to 35 fathoms depth, chiefly between Sanda Island and Ailsa Craig.

I would here acknowledge my gratitude to my colleagues for many valuable suggestions.

The excellent photographs in Figure 5 are due to Mr. Stokes, of the Ministry's staff.

SECTION A.

ON THE RELIABILITY OF WEIGHINGS MADE AT SEA.

Messrs. Salter's spring balances were used in the weighing work, the most useful sizes being those which weighed :—

(*a*) To the nearest gram, range 0–100 grams.
(*b*) To the nearest 10 grams, range 0–1,000 grams.
(*c*) To the nearest 100 grams, range 0–10,000 grams.

Livers and gonads were weighed by simply impaling them on the hook of the balance. The gutted fish were weighed by passing the hook under the gill-cover.

When weighing at sea, the pitching and heaving of the ship in the swell cause the object being weighed to become, apparently, alternately heavier and lighter. A reading was made by eye-interpolation between the swings of the pointer on the scale of the balance. But, since the movements of a ship are never regular, errors are produced by this method of taking a rough mean of several swings, and these errors tend to vary in such a way that some determinations are too heavy and some too light. By taking the mean of a series of such weighings, however, these positive and negative errors may be expected to cancel each other out, leaving a resultant mean value which is very near the correct weight.

Even so, it was not expected that any great accuracy could be reached in weighings made at sea, in the weather conditions typically to be met with on the edge of the deep water, but experiments were made to test the order of absolute accuracy of such weighings.

Fifty pieces of scrap-lead, of weight ranging from 15 to 770 grams, were each stamped with a number. These lead scraps were weighed at sea in exactly the same conditions as those in which thousands of weighings have been carried out on hake. On coming ashore, or on anchoring in a still haven, the lead scraps were re-weighed carefully to find their true weight. The weights obtained at sea were compared with these true weights and the errors under different conditions found.

The results of these experiments came as a surprise, for, in 87 weighings, most of which were made in bad weather, the maximum percentage error was 14·6. In only 5 cases was the error greater than 10 per cent. and in 19 cases the weight found at sea was the correct one. The data are given in Table I, page 58. The table shows how some of the errors are positive, some negative.

The 87 weighings were made in three batches.

(i) Faroe-Shetland Channel, March, 1927. The wind was blowing strongly from the S.S.E. on the ship's port quarter. The ship therefore had a peculiar sidling and lurching movement, with a fairly severe heaving up and down, as each wave passed beneath her. The dispersion of the errors in 28 weighings was found to be :—

Correct	4
Less than 5 per cent. error	14
Less than 10 per cent., but more than 5 per cent.	10

The resultant mean error of the whole series was —1·0 per cent.

(ii) Butt of Lewis, April, 1927. The weather was very fine, with a light N.W. wind, and calm sea.

The dispersion of the errors in 30 weighings was :—

Correct	10
Less than 5 per cent. error	14
Less than 10 per cent., more than 5 per cent.	5
More than 10 per cent.	1

The resultant mean error of the 30 weighings was +0·4 per cent.

(iii) Rockall Bank, April, 1927. The weather was very bad, with a fresh N.W. breeze and a heavy tumbling sea. The ship was towing her gear head to wind, and pitching so violently that I was thrown off my feet once.

The dispersion of the errors in 29 weighings was :—

Correct	5
Less than 5 per cent. error	11
Less than 10 per cent., more than 5 per cent.	9
More than 10 per cent.	4

The resultant mean error of the 29 weighings was +1·6 per cent.

It is clear, from these experiments, that, even in wretched weather conditions, mean weights of a high order of accuracy can be obtained and, since the mean values used in Section D are usually based on a very considerable number of weighings, I am confident that the mean weights do not differ materially from such as would have been obtained from weighings made ashore. Moreover, whenever possible the most favourable conditions for weighing were chosen ; for example, in bad weather, weighings would be made while the ship was towing before the wind and sea, when her movement, of course, is much slower and more regular than in any other position. The great advantage of doing the weighing at sea has been that I have been able to deal with absolutely fresh material, to find the sex, and weigh the gonads and livers, whereas working ashore, one can obtain only gutted hake which have, moreover, often been in ice for days.

It appears, also, that experience is not necessary in making accurate weighings at sea, for in Table I are also given the weighings made by my friend Mr. Syd Leech, of the Fleetwood Fishing-Vessel Owners Association. Of 20 weighings, 5 were correct, 6 were less than 5 per cent. in error, 7 were more than 5 per cent. but less than 10 per cent. in error, and 2 were more than 10 per cent. in error. The resultant mean error in the series of 20 weighings was +3·4 per cent.

Some 12,500 hake have been dealt with in this way, involving 37,500 weighings at sea.

SECTION B.

ON THE MATURATION OF THE GONADS OF THE HAKE.

1. Male hake become mature very early in their life history. Some counts of mature and immature males were made during the cruises of the " George Bligh " to the hake grounds in August, 1928. These counts are set out in Table II, page 59.

Counts were made on three grounds, namely off Galley Head, on the Bull grounds, and in Galway Bay. Off Galley Head and in Galway Bay the males were mostly still spawning. On the Bull grounds they were spent. The three groups of counts are combined in Table II. It is seen that the proportion of mature males reaches 50 per cent. at 27 cms. The earliest mature male was 20 cms. in length, but it is difficult to define the higher limit of immature males; the counts have no doubt included some spent mature males, which are often impossible to distinguish from immature males, since the testis is very small in such small fish. It is safe to conclude that all males are mature at 50 cms. and that maturity sets in at about 27 cms. Birtwistle and Lewis (1925) found, in late July and early August, male hake, off the South of Ireland, commencing to mature at the 20-24 cms. group and that, at the 40-44 cms. group, all males were mature. Belloc (1923) has found male hake maturing at 19 cms. The remarkably early maturity in male, as compared with female, hake, appears to be well established.

2. In female hake, the ovaries are fairly easily classified by their size, colour and general naked-eye appearance. It has even been possible to classify them into immatures, adolescents (or ovaries ripening for the first time) and matures. Adolescent and mature females are further subdivided into classes according to their degree of advancement towards ripeness.

Arbitrary Classification of Hake Roes.

Immature.	Adolescent.	Mature.
	1. Commencing. 2. Intermediate. 3. Advanced.	1. Spent. 2. Recovering. 3. Ripe. 4. Running.

Graham (1923) classifies the gonads of the cod by their colour, and justifies his classification by an examination of sections cut from them, stained and examined under the microscope. I find that my classification of the roes of the hake is justified by a comparison with the mean weight of the roe, and with the commercial landings of ripe roes, as shown in Figures 1 and 2. The seasonal changes in the ovaries can, therefore, be followed by an inspection of the frequency of the different stages of ripening, as well as by following the changes in mean weight.

Three curves are drawn in Figure 1. They show, respectively, the mean monthly landings of hake roes at Cardiff, 1923-8 (thin line, data in the Appendix, Table IXA), the mean weight of the ovary in mature hake of 80-89 cms. (thick line, data in the Appendix, Table VIA), and the percentage of ovaries in the arbitrary " ripe " stage (pecked line, data in the Appendix, Table IV). The three curves are in good agreement.

Two curves are drawn in Figure 2. They show respectively the mean weight of the ovary in adolescent females of 70-79 cms. (continuous line, data in the Appendix, Table VIA), and the percentage of ovaries in the "advanced" condition

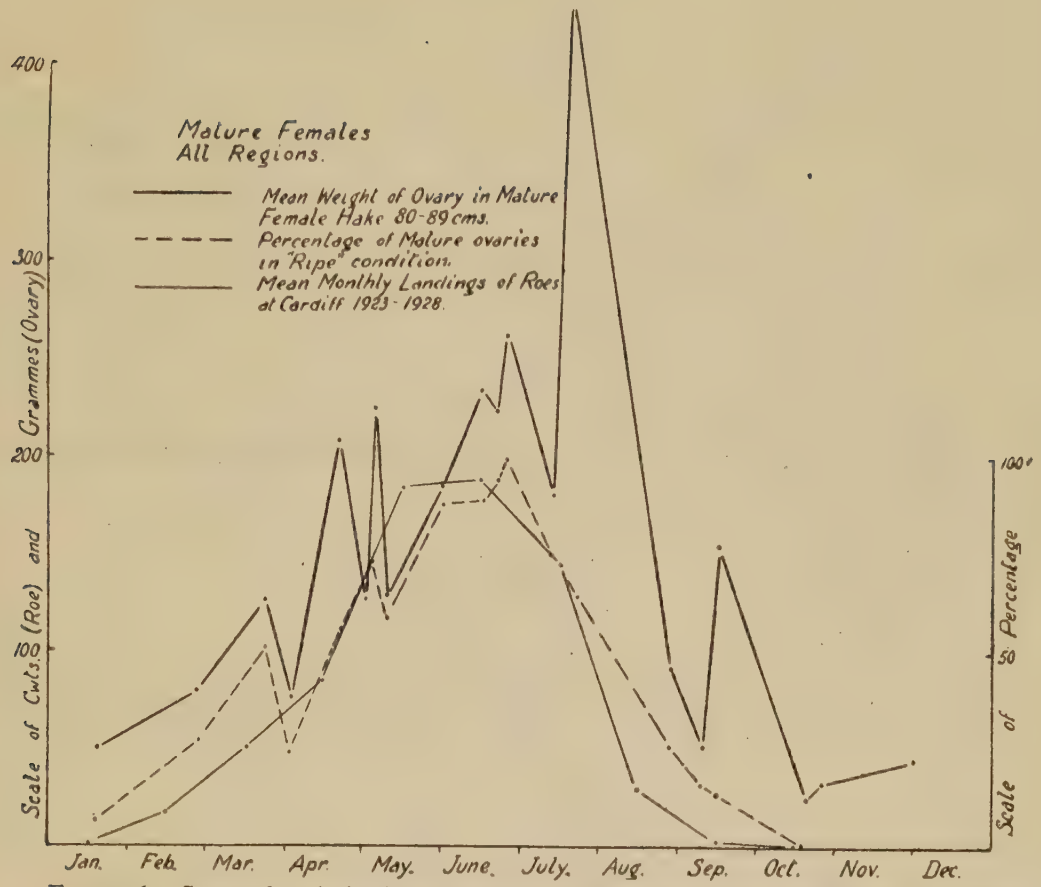


FIGURE 1.—Seasonal variation in the percentage of mature ovaries in the "ripe" condition, in the mean weight of the roe of mature females of 80–89 cms., and in the weight of roes landed at Cardiff, mean of years 1923–8. Data in the Appendix, Tables IV, VIA. and IXA.

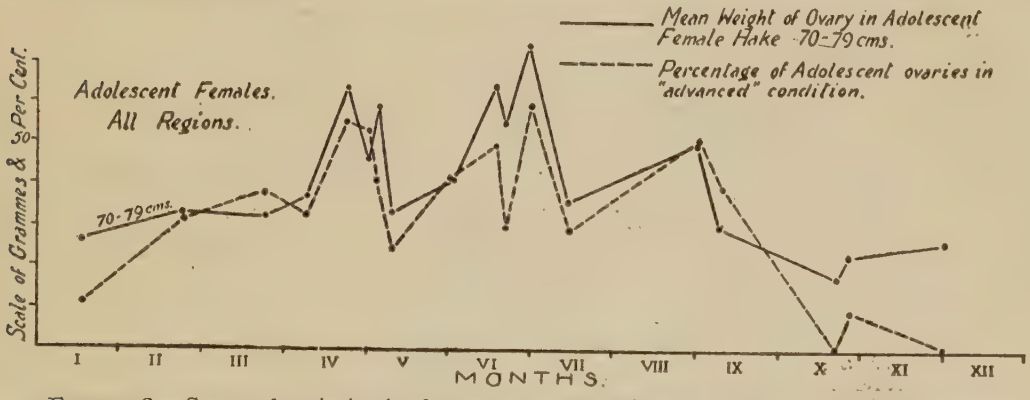


FIGURE 2.—Seasonal variation in the percentage of adolescent ovaries in the "advanced" condition, and in the mean weight of the ovaries of adolescent female hake. Data in the Appendix, Tables IV and VIA.

(pecked line, data in the Appendix, Table IV). Again the two series of observations are in excellent agreement, and afford a justification of the use of my arbitrary maturity stages.

The length at which adolescence and maturity set in among female hake may be seen in Figure 3 (data in the Appendix, Table V).

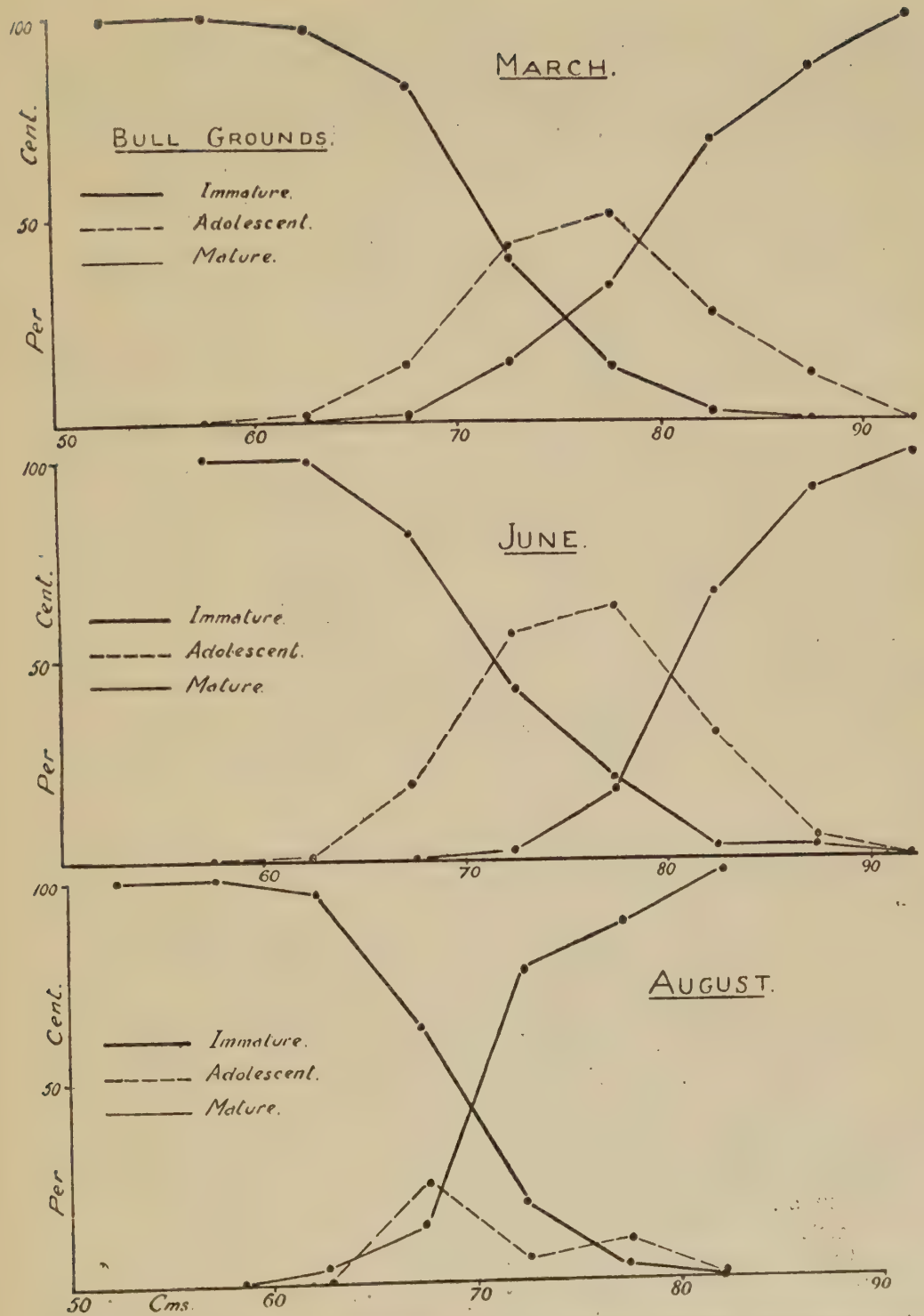


FIGURE 3.—Percentage of immature, adolescent and mature females at the 5-cms. groupings. Bull grounds. Data in Appendix, Table V.

In Figure 3 there are three sets of curves. They show the percentage of immature, adolescent, and mature females, in each 5 cm. group, at three separate seasons,

on the Bull grounds, namely in March, June and August. In the March and June curves, both adolescence and maturity set in between 60 and 70 cms., though the immature females extend to the 85-89 cms. group, and 100 per cent. mature females is not reached before the 90-94 cms. group. In the August curve, adolescent females are clearly relatively less abundant than in March and June, and extend

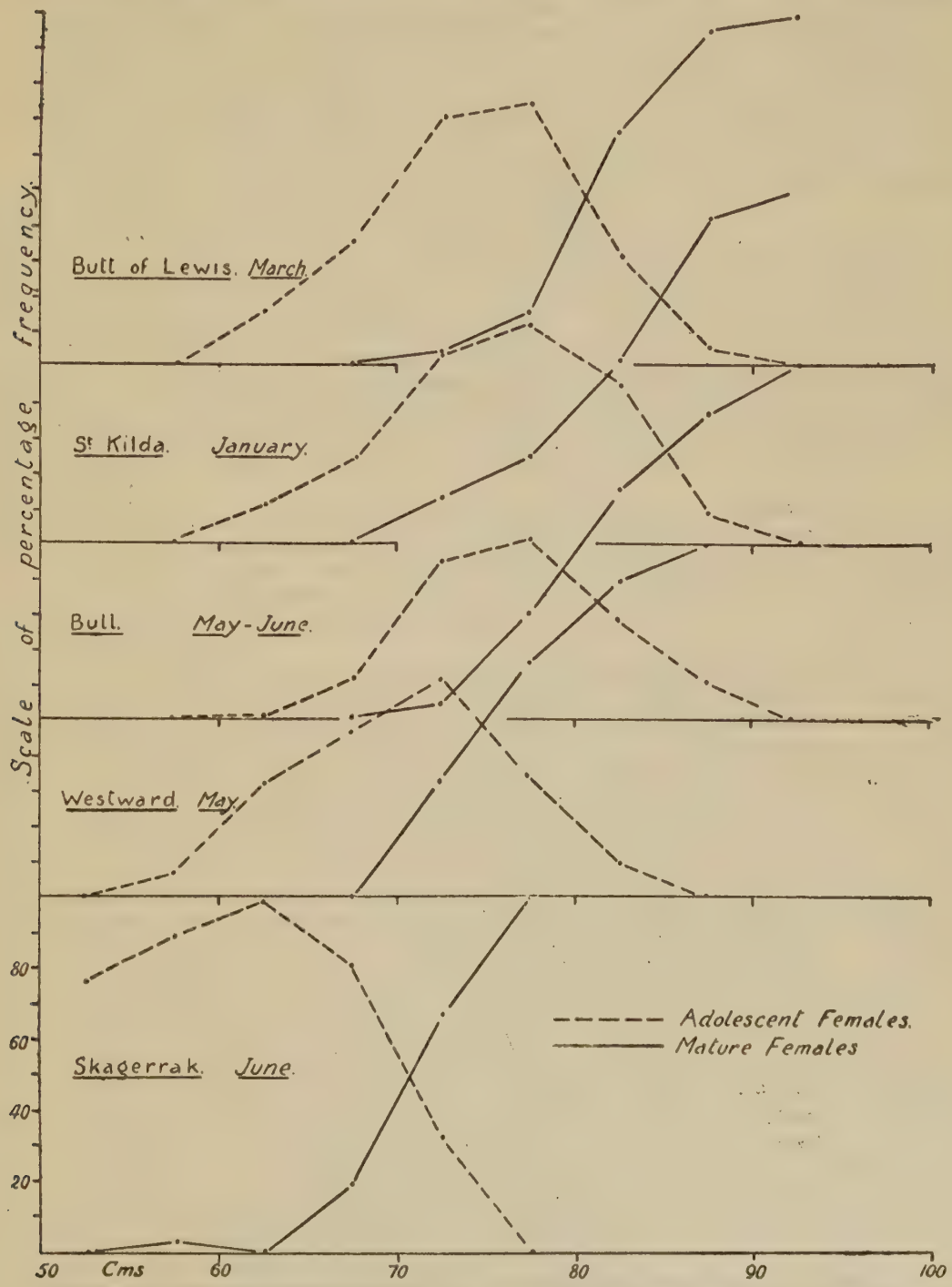


FIGURE 4.—Regional variation in the onset of adolescence and maturity in female hake Data in Appendix, Table V.

only to the 80-84 cms. group, while mature females extend down to the 55-59 cms. group. The data are given in the Appendix, Table V.

There is also, however, a regional variation in the onset of maturity. This may be seen in Figure 4.

Five series of curves are drawn in Figure 4. The data are to be found in the Appendix, Table V. They show the percentage distribution of adolescent and mature females, in the 5 cm. groups, on five deep-water hake grounds, namely, the Butt of Lewis, St. Kilda, the Bull, the Westward, and the Skagerrak. The positions of the first four grounds may be seen in the Chart in the Frontispiece. The distribution of the adolescent females shows little variation as between the Butt of Lewis, St. Kilda and Bull grounds, but the most southerly ground, the Westward, shows a distinctly earlier onset of adolescence (confirmed by the February data in Table V), and finally the Skagerrak sample shows a very early onset of adolescence and maturity (confirmed by the Norwegian Deep sample, Table V).

Thus there are regional as well as seasonal variations in the length at which sexual maturity sets in, in the female hake, but generally speaking, adolescence and maturity set in between 60 and 70 cms., and immature females are not met with at lengths greater than the 85-89 cms. group. The whole range of maturity stages therefore falls within the lengths dealt with in this paper (*i.e.* 50 cms. and greater).

Birtwistle and Lewis (1925) found that maturity began to set in, among females, in the 55-59 cms. group, and that all are mature after the 70-74 cms. group. Belloc (1929) states that the hake becomes adult at 20 to 25 cms. and has clearly overlooked the remarkable difference in the onset of sexual maturity as between males and females.

The arbitrary maturity stages will now be described. They were based on the naked-eye appearance of the roes, and in order to define them histologically, portions of the roes have been fixed in Bouin's fluid from time to time, and serial sections cut, stained and examined under the microscope. Some of these sections have been photographed and reproduced in Figure 5. The stains used were Iron Haemotoxylin and Eosin.

The development of the ovarian eggs of Teleosts has been extensively studied, notably by Cunningham (1893-5), Fulton (1897), Franz (1910), and recently by Wheeler (1924), who, however, was mainly interested in yolk formation. The main course of events is very similar in all species studied, and controversy exists chiefly about such points as the origin of the oocytes which give rise to the successive annual crops of eggs, and cytoplasmic changes in the young developing egg. Some remarks on the oocytes of the hake will be made in Section C.

Immature ovaries of the hake appear to the naked eye as small oval bodies, pale yellow in colour, translucent, and with a thin, smooth skin, free from wrinkles. In female hake of very small size, less than 20 cms., the ovary is difficult to distinguish from the testis. In the smaller immature females, sections of the ovary reveal active mitosis among the oogonia, and the appearance of the oocytes ; in the larger immature females, such as those dealt with in this report, the ovigerous lamellae are seen to be full of young eggs, with a large nucleus containing many peripherally-arranged nucleoli, and very deeply-staining cytoplasm (see Figure 5*a*).

The first naked-eye indication of the onset of maturity is a loss of transparency without loss of colour. The ovary is no longer a clear yellow, but a turbid yellow. As yet there is no increase in size. Such ovaries have been defined as " commencing." When serial sections of such ovaries are examined, it is seen that many of the eggs have enlarged and have sunk into the connective tissue of the ovigerous lamellae ; the follicular epithelium first becomes noticeable about these eggs. Their cytoplasm appears much enlarged and no longer deeply-staining, but staining only palely—the reason for this is that the cytoplasm is spread out over the surfaces of what have been very numerous vacuoles. A microscopic examination of the fresh living material in this condition shows that, in the cytoplasm of the active eggs, a ring of oil

EXPLANATION OF THE PLATE—FIGURE 5.

All sections fixed in Bouin's Fluid, and double-stained with Iron Haemotoxylin and Eosin. The bluish haemotoxylin has photographed comparatively pale, the reddish eosin comparatively dark.

a. Immature Female. 50 cms., St. Kilda, January, 1926. The ovigerous lamellae contain, applied to their under surfaces, an enormous number of oogonia and young oocytes, and, sunk below into the stroma, a number of eggs, with enlarged nucleus, and deeply-staining cytoplasm. × 43.

b. Adolescent Female. 75 cms., "intermediate," St. Kilda, January, 1926. The ovigerous lamellae have greatly increased in length and thickness, and the oocytes and young eggs are apparently few. The stroma contains developing eggs, with large nucleus, and cytoplasm staining palely, owing to the formation of numerous oil-vacuoles. × 49.

c. Adolescent Female. 56 cms., "advanced," Norwegian Deep, June, 1928. A few of the eggs have shown a great increase in size, with abundant laying-down of yolk and oil droplets, and the formation of the egg-membrane, but the vast majority are still in the condition seen in sections "a" and "b." Compare with section (f), which is the corresponding stage in the mature roe. × 29.

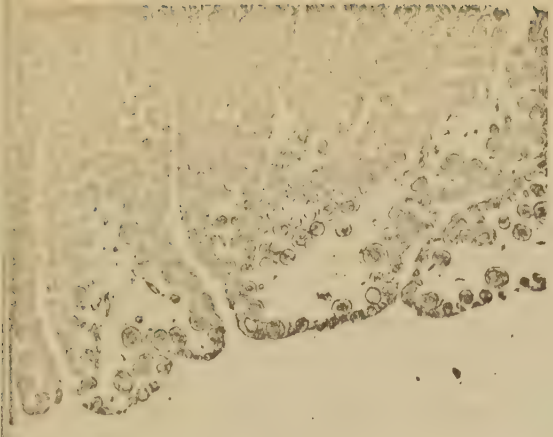
d. Mature Female. 66 cms., newly-spent, Donegal Bay, September, 1927. Numerous empty follicles may be seen in the collapsed lamellae, which also contain, applied to their surfaces, abundant young eggs, too small to be seen distinctly under the magnification used (*see*, however, the measurements in Table III). × 48.

e. Mature Female. 82 cms., "spent," Bull grounds, November-December, 1925. There are traces of degenerating follicles and, sunk in the stroma, may be seen numerous eggs in an early stage of ripening with palely staining cytoplasm. The ovigerous lamellae are shrunk, and applied to their surfaces are abundant young eggs, too small to be seen distinctly under the magnification used (*see* measurements in Table III). × 48.

f. Mature Female. 76 cms., "ripe," Skagerrak, June, 1928. The ovigerous lamellae are enormously distended, and contain eggs in all stages of ripening. The more advanced eggs have a very distinct follicular epithelium, a conspicuous egg-membrane, and cytoplasm crowded with yolk granules and oil vacuoles. Young undeveloped eggs are very few in the section. × 48.

g. Mature Female. 85 cms., "recovering," Westward ground, August, 1928. An early stage in the degeneration of the unspawned eggs. The chromatin of the nucleus, and the yolk of the cytoplasm form irregular masses, and the egg-membrane and follicular epithelium have broken down. × 48.

h. Mature Female. 77cms., "recovering," Bull grounds, November-December, 1925. Later stage in the degeneration of the unspawned eggs. The follicular epithelium has disappeared, and the margins of the eggs are infiltrated with phagocytes and blood-vessels. × 48.



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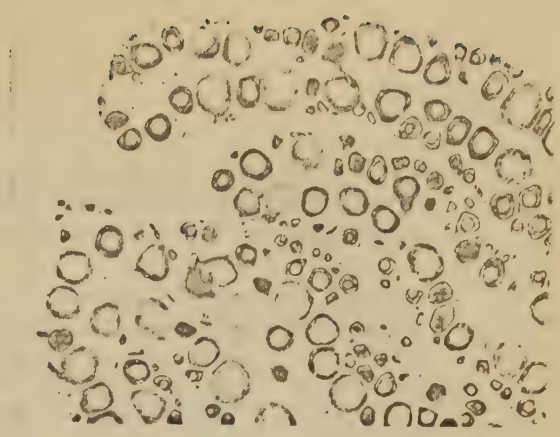

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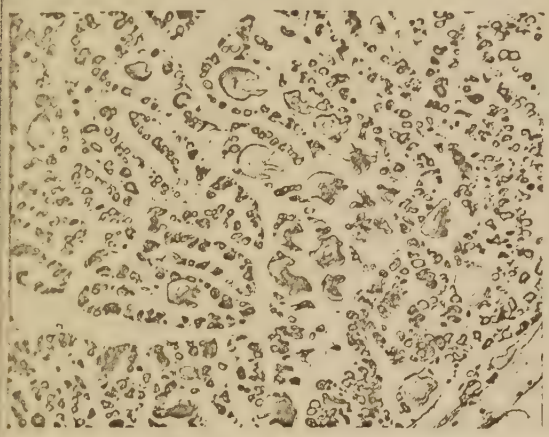

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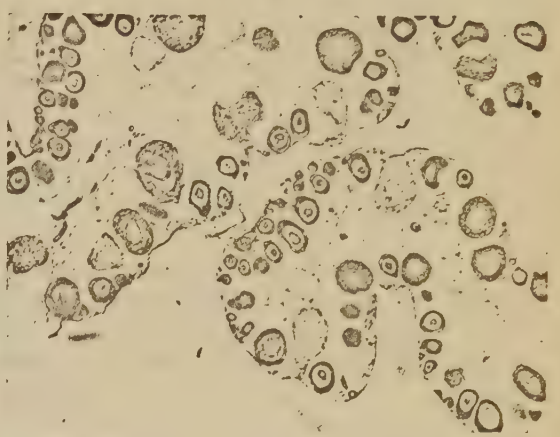

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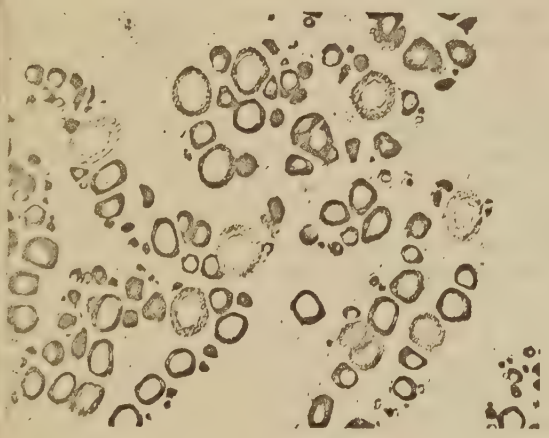

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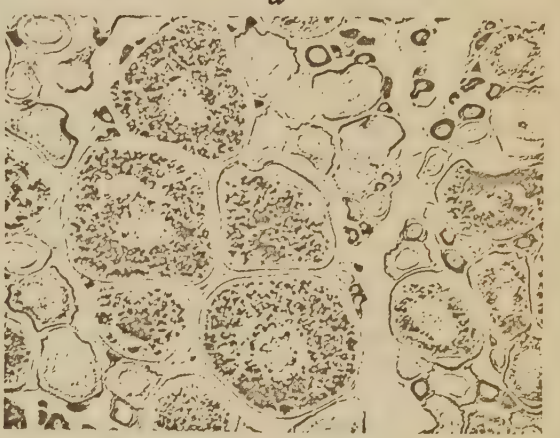

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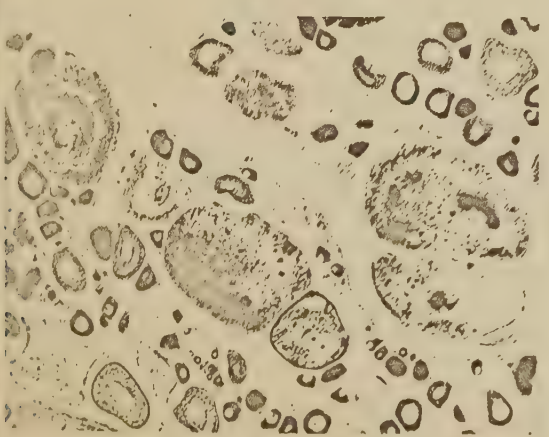

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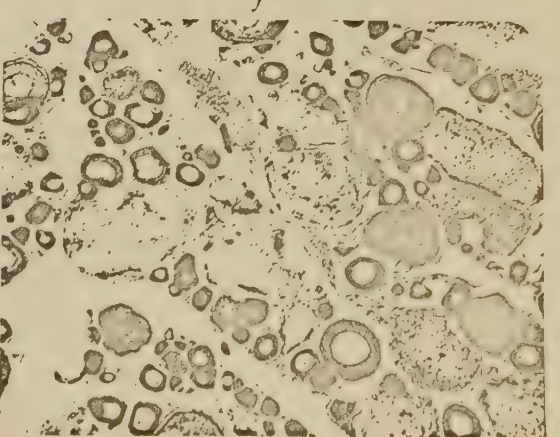

h

globules has appeared immediately outside the nuclear membrane. This ring of oil globules appears quite black, owing to their great number and minute size, and I have no doubt that it is these oil globules in the cytoplasm of the active eggs which give the ovary, as a whole, its turbid appearance.

A somewhat later stage in the ripening of the ovary for the first time is manifested to the naked eye as a mass of tiny white spots seen through the transparent skin of the ovary. When such ovaries were noticed for the first time, I was uncertain whether the white spots were ripening eggs or degenerating eggs. A study of the seasonal distribution of these ovaries, as well as an examination of stained sections, shows that, while in some cases the white spots were degenerating ova which were being resorbed, especially in the early autumn, in the majority of cases the white spots were active eggs in a more advanced stage of development than in the " commencing " ovary. The sections show that there is a considerable quantity of yolk in the peripheral cytoplasm of the enlarged eggs, that the follicular epithelium is now distinct, with numerous flattened nuclei, and that the egg-membrane is beginning to thicken. These features combine to render the egg opaque and white by reflected light, and it has now enlarged sufficiently to be visible to the naked eye as a white dot. At this stage the whole ovary begins to increase in size. This is the stage denoted " intermediate." (Figure 5 *b*.)

At the next stage the whole ovary has swollen to several times its original volume and the enlarged eggs have become so numerous that the translucent spaces of ovarial stroma have become obliterated to the naked eye. The eggs therefore form a continuous opaque mass which appears pink in colour when seen through the thin distended wall of the ovary. This is the stage denoted " advanced."

Figure 5*c*, which is a photograph of a section of an ovary in this condition, shows that only a small number of eggs have undergone this enlargement and yolk-formation. It should be compared with the photograph of a section of a mature ovary, 5*f*.* There is good reason to believe that these three stages, which form, in adolescent females, a series in ascending order of ovarian activity, do not lead on to spawning in the same season as they set in. An inspection of the data in Table IV. shows that many adolescent ovaries never develop beyond the " commencing " stage, others no farther than the " intermediate " stage. The adolescent phase, in short, is a tentative pre-spawning maturation, which closely reflects the spawning rhythm in mature female hake, but does not lead to spawning. The advanced yolky eggs break down and degenerate, and the adolescent ovary may then take on the appearance of a spent mature ovary, and thenceforward be classed among mature ovaries. But, at some time during the first true maturation which succeeds the adolescent phase, there is a hypertrophy of the unstriped muscle in the wall of the ovary, which, by its consequently greater thickness, allows of little further difficulty in recognising such an ovary as mature.

Adolescent ovaries have been distinguished from mature ovaries, therefore, by their general naked-eye appearance, by their smaller size (in spite of their obvious activity), and by their thinner walls (giving a rosier pink colour in advanced ovaries of this class than in the corresponding stage in mature ovaries). None the less, there is a time, when the mature ovaries are spent and collapsed, and when the past season's adolescent ovaries have re-absorbed their yolky eggs, when it is difficult to distinguish between immature, adolescent and even, in some cases, mature ovaries. The same difficulty arises in other fish. Graham (1924) says, of the Cod, " it is impossible to distinguish small spent fish from immature fish " though " in the larger fish, where the shrunk spent gonad has a visible thick skin, there is no difficulty." Holt (1895) acknowledges the difficulty, but states that " it does not appear that it (the ovary of a shotten fish) ever regains the appearance of immaturity," but Cunningham

* Allowance must be made for the difference in magnification in the two figures.

(1893-5) considers that it is not always possible to distinguish between them. Johnstone (1910) also finds it difficult to say whether females are, or are not, mature.

The "spent" ovary, which is the starting point in the second and subsequent advances to maturity, is usually easily recognisable by its collapsed condition, the thickened wall of the ovary being thrown into folds, and dead white in colour. In sections of such spent ovaries, the ovigerous lamellae are seen to contain very numerous eggs already enlarging and secreting oil and yolk droplets. (Figure 5*e*). There are few signs of the degenerating follicles of the previous spawning season's eggs: in order to see these well, it is necessary to examine an ovary which has obviously shed its eggs very recently. (Figure 5*d*). The empty follicles in the ovary of the hake, as in the other species investigated by the authors named, therefore disappear rapidly. The collapsed follicles soon become infiltrated with phagocytes, in the hake.

In some spent ovaries, a considerable number of eggs may be seen being reabsorbed and I have already stated that the advanced yolky eggs of "adolescent" females are reabsorbed. In the case of the mature fish, the reabsorbed eggs are those which have presumably ripened too late to be spawned, or have for any other reason been unable to complete their ovarian development. Cunningham (1895-7) finds the same process taking place in the ovaries of mature Plaice between spawning seasons. The process of resorption seems to take place in two stages. Firstly, the structure of the nucleus and the cytoplasm breaks down; the chromatin may form a shapeless mass in the centre of the egg, and the egg-membrane and nuclear membrane disappear. The yolk forms large irregular droplets scattered about in the cytoplasm. These changes take place of course while the egg is still contained in the follicle. (Figure 5*g*). At a later stage in the degeneration of the egg, and early in the resorption of small eggs, masses of phagocytes invade the follicle, and there can be little doubt that these are the chief agents in the breakdown of these redundant eggs, especially in the later stages. (Figure 5*h*). These observations on the resorption of the eggs agree with those of Franz (1910), who saw phagocytosis, and of Wheeler (1924).

The first sign of recovery in a spent ovary is a filling out and a disappearance of the wrinkles. The rapidly enlarging eggs become yolky, and, commencing to show through the dead-white walls of the ovary, give it a light pink tinge. This "recovering" stage sets in very soon after spawning, so that "recovering" fish appear almost simultaneously with "spent" fish. The histological details in a recovering ovary are identical with those already described in the adolescent ovary, except that occasionally the last traces of a degenerating follicle may be seen.

This process of recovery leads on to a stage in which the ovary has increased to many times its weight and bulk when compared with the spent condition. The contained eggs are white and yolky and easily visible individually to the naked eye (Figure 5*f*.). By their increase in size they have distended the ovary wall and show bright pink in colour through it. This stage has been called "ripe." Ovaries in this condition have a certain commercial value, and considerable quantities are landed during the season prior to spawning. It has been shown, in Figure 1, that there is a good agreement between the mean monthly landings of hake roes and the percentage of mature females with "ripe" roes, as found in the present investigations.

The final stage in the ripening of the eggs is when they burst free from the follicle, and come to lie in the lumen of the ovary. Fulton (1890) mentions the "more or less sudden increase in bulk which occurs in the ovum shortly prior to its extrusion," which "seems to be due to sudden accession of fluid from the ovarian follicles, which increases the bulk of the ovum and renders the opaque contents clear by dilution." Milroy (1897) in commenting on a later paper of Fulton's, says that "the increase in volume . . . from the opaque immature to the transparent or translucent mature ova, varies from about 1 :3 to 1 : 5." With such a great increase in the volume of the individual eggs, it is not surprising that the ovary of a hake,

containing eggs in this final stage of maturation, is enormously distended, and will burst open at the slightest touch. In some cases the eggs may be seen actually running out from the vent; ovaries which contain large transparent ripe eggs have been defined as "running."

My observations have led me to believe that not only is the change from opaque immature to transparent mature eggs a sudden one, but that the extrusion of the eggs follows as quickly. I have found few intermediate stages between an ovary containing "ripe" eggs and one containing "running" eggs; and secondly, among 1,932 mature female hake dissected on the deep-water hake grounds, only 26 were found in the "running" condition. The percentage of "running" ovaries was never higher than 6 even at the height of the spawning season, in the deeper water at least. Now it is certain that the hake does spawn in, or over, the deeper water. Schmidt (1908) has found the very young fry of the hake at over 1,000 metres depth, and Belloc (1929) states (without giving any particulars however), that very young larvae of hake have been found over depths of 4,000 metres. Clark (1923) suggested that, in deeper water, spawning may take place at intermediate depths, where a trawl would not take the spawning fish, and thus account for the rarity of spawning hake in the catches. The only occasions on which I have seen large numbers of female hake actually running with eggs they have been caught in shallow water as, for instance, in 30 fathoms off the Saltee Islands, and at the same depth in the Firth of Clyde. In the latter case, no fewer than 27·2 per cent. of the mature females were in the "running" condition (Table IV.) It would therefore seem quite likely that ripe female hake spawn at intermediate depths, over deep water, though as I have stated in Part I of this series, hake usually run into shallow water to spawn. But it seems equally likely to me that spawning females are so rarely met with, because the eggs, as they ripen in batches, are shed at once.

3. The seasonal variation in the frequency of the different maturity stages may now be discussed. Especial reference will be made to the easily defined stages, "ripe" in mature, and "advanced" in adolescent, females.

The data are to be found in the Appendix, Table IV. All the results of the voyages made on commercial trawlers have been included, but only one of the stations worked by the "George Bligh," in August, 1928, namely, that on the Bull grounds, since the commercial fleets were fishing here at the time of the research vessel's visit to the area, and it has been explained, in the Introduction, that the location of the commercial fleets is taken to indicate the position of maximum density of the hake at any given time.

The data referring to the arbitrary maturity stage "ripe" in mature females are plotted, in seasonal order, in Figure 1. The plotted points refer to grounds having a geographical range from the latitude of the English Channel (Westward ground) to that of the north of Scotland, and the Norwegian coast, and to the years 1925 to 1929 inclusive. Yet Figure 1 shows that the plotted points form a fairly regular curve, and one may conclude that the ripening of the ovary is more or less simultaneous over a wide geographical range, and is constant from year to year. This conclusion is confirmed by the seasonal variations in the mean weight of the ovary, and by an inspection of the commercial landings of roes (Figure 1 and Tables VIA and IXA). The names and positions of the chief deep-water fishing grounds are shown in the chart in the Frontispiece.

Figure 1 shows that the percentage of ovaries in the penultimate stage of maturation rises to a maximum in the summer (June or July), and then declines to nil in October. This gradual increase and decrease in the percentage of "ripe" roes, confining itself to one season of the year, is consonant with a spawning season at its height in July, though actually spawning hake (in the "running" condition) were found spasmodically, as Table IV shows, from March to September, and I

have even found female hake, still spawning, in Donegal Bay, as late as early November.

An inspection of Table IV will show that, as might be expected, " spent " females are most abundant in the months from October to January ; but the females in the " recovering " condition show an interesting feature in that, in early autumn (August and September) there is an increase in their numbers not consistent with a true recovery after exhaustion. These fish were probably partially spent, but not sufficiently so to be classed as " spents," and, by their similarity to true " recovering " fish, were classed as such.

In Figure 2, the data referring to adolescent females in the " advanced " condition are plotted in seasonal order. This arbitrary maturity stage corresponds to the " ripe " stage in mature females, and Figure 2 shows that, as in " ripe " females, the percentage rises irregularly to a maximum in June, though the seasonal variation is small as compared with mature females. These results are confirmed by the variations in mean weight of adolescent roes, with which they are in close agreement. The abortive pre-spawning maturation of adolescent female hake, therefore, closely foreshadows the true maturation of mature females.

The percentage of " commencing " ovaries tends to show an increase to a maximum in the autumn, while the percentage of " intermediate " ovaries tends to remain stationary. But there are probably regional variations in the proportions of the three classes of adolescent females, thus, in the months from March to May, the Bull samples tend to have a higher proportion of " advanced " ovaries, and a lower proportion of " commencing " ovaries, than those from the westward ground and the northern hake grounds. This is probably because the depths worked on the Bull grounds at this time were less than those worked on these other grounds, and it will be shown, in Section D(6), that there is a relation between the weight of the gonad, and the depth of capture, such that fish with more advanced roes are found in shallower water than fish with less advanced roes.

The most important points in connection with adolescent hake, as deduced from Figure 2 and Table IV, are, firstly, the reflection, in adolescent hake, of the maturation of mature hake, an activity in the ovary reaching its maximum in June or July, and, secondly, an increase in the proportion of the ovaries in the earliest stage of ovarian activity to a maximum in the autumn. This may be seen in Table IV ; Table V shows, likewise, that the numbers of adolescent females become high, and extend far down the scale of length, in the autumn, when the mature fish are recovering from exhaustion (Bull grounds, October and November-December, Table V). These two facts, taken together, show, in my opinion, that, in the autumn, when the mature females are commencing to recover, a new batch of immature females begins the cycle of adolescence, while the previous year's adolescent females, with their yolky eggs re-absorbed, commence the advance towards their first spawning. Here again, then, the adolescent females reflect the cycle of changes in the mature females.

Hermaphrodites.

Johnstone (1907) reported, of a hermaphrodite hake which he examined, as follows : " both ovaries are present . . . They are apparently normal organs and crowded with small ova, and not dissimilar " in appearance " to the ovaries of a normal hake at the same stage of development." " At the posterior end of each ovary is a testis. These organs have the shape and appearance of a well-developed gadoid testis. Each is larger than the ovary to which it is attached." The lumen of the ovary was continuous with that of the testis.

Belloc (1929) finds hermaphrodites rare among hake. Of these, bilateral hermaphrodites were most common. The ovary is on the left, the testis on the right side of the fish. Only in one case was the reverse arrangement found, but Belloc

no data as to the frequencies of his hermaphrodites. He gives an excellent photograph of such a bilateral hermaphrodite, in which both ovary and testis were apparently functional, and also one of the rarer type described by Johnstone, in which on each side there is an ovary and a testis, the testis being posterior. Belloc is of opinion that the fish would probably behave as a functional protogynous hermaphrodite, since the ovary was in a riper condition than the testis, and both were apparently functional.

Among the 12,500 hake dissected in the weighing experiments which form the basis of Section D, only four hermaphrodites were observed. Two were 58 cms. in length and were found respectively in June, 1926, on the Bull grounds, and in August, 1928, on the Westward ground. Both were bilateral hermaphrodites; in both cases, the testis had all the appearances of ripeness, while the ovary was in the immature condition described earlier in this section.

The remaining two hermaphrodites were also bilateral hermaphrodites, and were both 77 cms. in length. One was taken on the Bull grounds in September, 1925, and the other off St. Kilda in January, 1926. Both testis and ovary appeared fully mature and functional.

In these hermaphrodites, therefore, the maturity of the male and female organs bore the same relation to length as if the hake had been unisexual. At 58 cms. the testis was mature, the ovary immature; at 77 cms. both testis and ovary were mature.

The liver and flesh of these four fish were decidedly heavier than the average male or female of the same size in the same sample, and, while the data are too few, of course, to be trustworthy, it is perhaps worth noting in connection with Belloc's statement that growth is very slow in hermaphrodites. He gives no data, however. The weights of the four hermaphrodites are given in Tables VIA and VIB, with their appropriate samples.

SECTION C.

ON THE APPARENT REGENERATION OF EGGS IN THE SPENT OVARY.

The development of the ovarian eggs of the hake is closely similar to that of the ovarian eggs of plaice, as described very fully by Franz (1910), if one omits his "third change-period," and "third rest-period." These stages are rejected by Wheeler (1924), who has shown that the cytoplasmic growth-rings, on which Franz based them, are artefacts due to fixation.

In hake, the later history of the oocyte seems to be as follows. The cytoplasm of the young oocyte, which is, at first, very small in quantity, forming a thin coating about the nucleus, and only staining lightly, if at all, with Iron Haemotoxylin, now increases in relative quantity, and stains deeply. The increase in size of the oocyte continues until the diameter is about 60μ. At about this stage, comparative quiescence seems to set in, and in older immature ovaries, in which mitosis has ceased, and in recently spent ovaries, eggs in this condition are everywhere abundant (see Figure 5 *d*, *e*). They seem to form, as it were, a permanent reserve fund of eggs, from which a certain number are withdrawn each spawning season, to resume activity, mature, and be spawned. In Section B, some description has already been given of the later stages in maturation of the season's crop of eggs.

A problem of great biological interest is the origin of the large number of young oocytes that appear in the spent ovary. Few young oocytes are to be seen in sections of ovaries containing eggs in an advanced stage of maturation, yet, when these eggs are shed, the ovigerous lamellae at once become full of young oocytes. "What has to be explained," writes Wheeler (1924), "is that a large crop of eggs is extruded each year by the mature fish; yet, at the following spawning, the number of eggs does not seem to have diminished." Cunningham (1893-5) writes, "it is also certain that the number of yolkless eggs left in the ovary after spawning is far less than the number shed in the following season. Consequently, the greater number of the eggs of one season's crop are produced *ab initio* during the year." Many workers have searched carefully for signs of mitosis in spent ovaries, by which the new crop of young oocytes might be regenerated, but without success. I have found no signs of mitosis in the mature ovary of the hake, at any stage and, in the hake, it cannot be said that the number of yolkless eggs left in the ovary after spawning is less than the number spawned in the following season.

I suggest that the sudden re-appearance of young oocytes in the spent ovary, after their apparent scarcity in the ripe ovary, is an illusion, consequent upon the collapse of the ovigerous lamellae after the ripe eggs have been spawned or reabsorbed.

I have already stated that portions of ovaries, at various seasons, have been fixed in Bouin's fluid, stained, and cut into serial sections. I have made measurements of the diameters of eggs in such sections. Eggs in which the knife had not passed fairly through the nucleus were not counted, and the measurement of the diameter of all eggs which had been cut more or less exactly through the middle was made along the longest diameter. The eggs measured were unselected as to size, except that the oogonia and very young oocytes (which are too small to be measured under the same magnification) were not counted.

The results of three of these counts are to be found in Table III, and in Figure 6.

The uppermost curve represents the frequency-distribution of the diameters of 118 eggs measured from the section of an ovary fixed in Donegal Bay in September, 1927. The fish was obviously newly-spent, not only by the naked-eye appearance

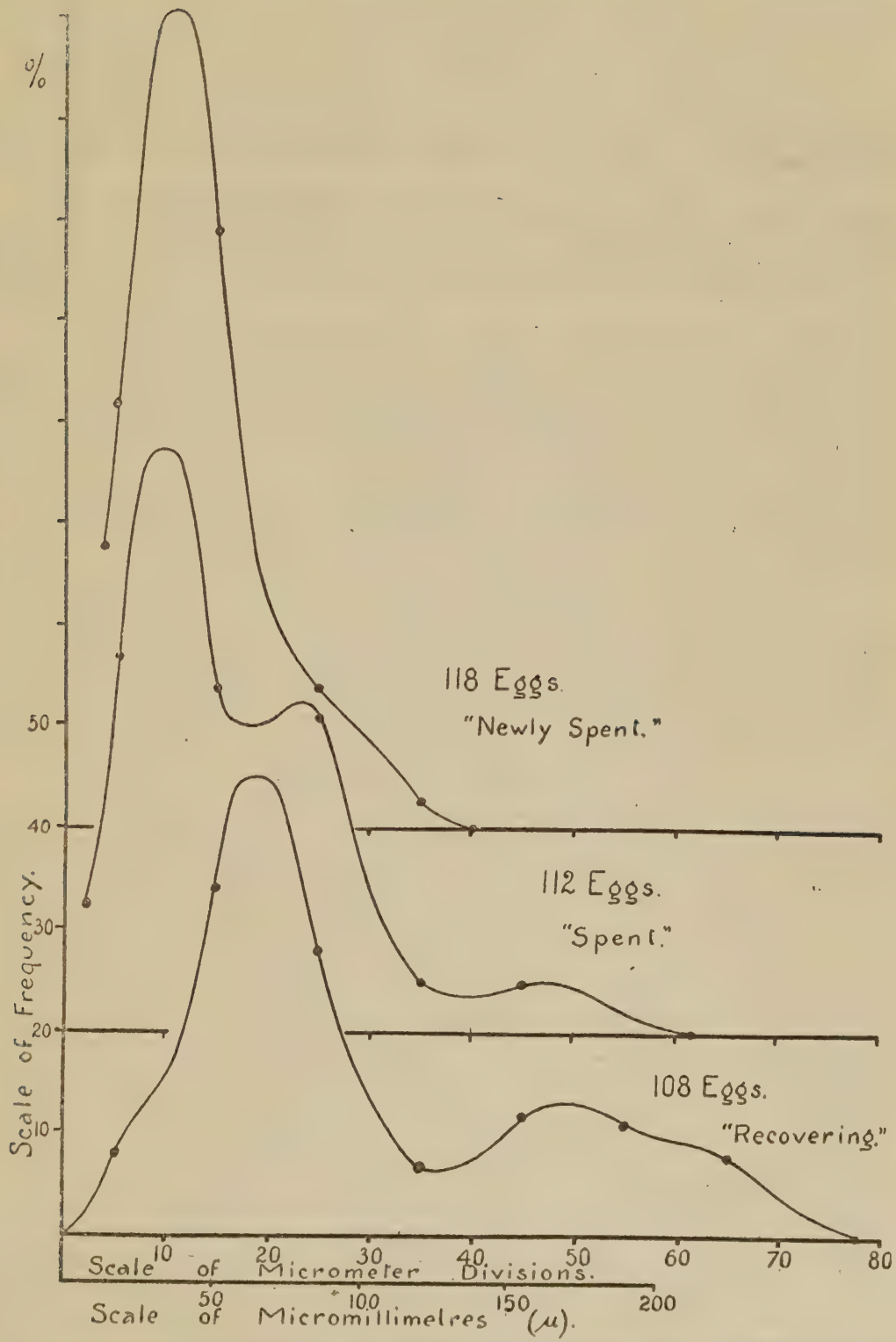

FIGURE 6.—Frequency-curves of the diameters of the ovarian eggs of hake, measured in sections of three ovaries in increasing order of ripeness. Data in Table III.

of its ovary, but by the presence, in the sections of the ovary, of abundant empty follicles. The diameters of the measured eggs give a mode of about 40μ, and a second higher mode, indicated by a flattening of the curve, at about 100μ.

The middle curve is the curve of distribution of the diameters of 112 eggs measured from the section of an ovary fixed at St. Kilda in January, 1926. This ovary was in the spent condition, but commencing to recover for the next season's spawning. The curve is distinctly trimodal, with modes at about 30μ, 80μ, and 170μ.

The lowermost curve gives the distribution of the diameters of 108 eggs measured from an ovary fixed at St. Kilda in January, 1926. This ovary was well on the way to recovery. The curve is still trimodal, with modes at about 30μ, 70μ, and at about 170μ. There is also a suggestion of a fourth mode at an even greater diameter, about 220μ.

To sum up, in the uppermost curve we have a very large mode at about 40μ, and a lesser mode at about 100μ; in the second curve, a mode at about 30μ and a lesser mode at about 80μ, though the second mode is very much greater in proportion to the first mode than in the uppermost curve; and in the lowermost curve there is a slight mode at 30μ and a dominant mode at about 70μ. In addition, in the middle and lower curves there is a mode at a much greater diameter, namely, about 170μ. These results are confirmed by measurements of the eggs in many other ovaries.

Confining our attention, for the moment, to the position of the modes, we may see that there is always a mode at about 70-100μ. It is these eggs which have been referred to as the reserve fund of eggs. A certain number of these become active, and undergo a great increase in diameter, as the ovary recovers in preparation for the next season's spawning. These enlarged active eggs give a mode, in the middle and lower curves, at about 170μ. Figure 6 shows how the active eggs, by their increase in diameter, become distinguishable from the reserve fund eggs, and form a distinct mode. (The increase in diameter goes far beyond the state of affairs shown in the third curve, but at later stages of recovery, the diameter of the active eggs becomes so huge (400-500μ), that very few are present in any given section of an ovary, and a count becomes impracticable).

But in the curves, in Figure 6, there is also a mode at about 30-40μ. In my view, these are eggs which are developing from the oocyte or young egg stage to join the reserve fund of eggs. By their addition to the reserve fund, the modal diameter of the latter is progressively reduced, until, when the process is far advanced (lowermost curve), it has been reduced from 100 to 70μ. As mentioned above, this reduction in modal diameter of the reserve fund eggs is also due, in part, to the withdrawal of a certain number of these to undergo maturation and spawning.

Now, to take the lowermost curve as an example, the increase in diameter of the active eggs has been from, say, 70μ to 170μ. But this means an increase in volume from ·00013 cubic millimetres to ·00193 cubic millimetres, or nearly 15 times the volume. And it must be remembered that the third curve in Figure 6 represents the active eggs at a very early stage in their maturation; the ovarian egg, according to some measurements I have made, has an average diameter of 460μ in the penultimate stage of maturation. The volume of an egg of this size is ·0382 cubic millimetres, and the increase in volume undergone since the "reserve fund" stage is therefore about 300-fold. It will be easily understood that the ripening of the active eggs will enormously distend the collapsed ovigerous lamellae of the spent ovary, with a relatively still greater increase in their surface area. But the reserve fund eggs, and the vast numbers of smaller eggs and unchanged oocytes, lie closely applied beneath the surface of the ovigerous lamellae. The result of this is, that the reserve fund eggs and young oocytes, which appeared so closely crowded together, and therefore so abundant, in the collapsed spent ovary, are now spread out over the enormously increased surface of the ovigerous lamellae, and comparatively few will appear in any given section of such an ovary. It is for this reason, I think,

the younger eggs have been overlooked, or considered very rare, in ripe ovaries, whereas their reappearance in the spent ovary seems sudden, an appearance *ab initio*.

It is for the same reason that the modes in Figure 6 are distorted out of their true proportions. In the collapsed newly-spent ovary, the young eggs enlarging towards the "reserve fund" size are very abundant in sections, the reserve fund eggs comparatively scarce. As recovery begins, and the ovigerous lamellae begin to increase in size and surface area, owing to the enlargement of the active eggs, the smaller eggs become relatively fewer in sections and, therefore, show a relatively less dominant mode. The number of "ripening" eggs in the ovary, before any spawning season, is probably only a small proportion of the "reserve fund" eggs.

Therefore, by my account, there are, in the early stages of recovery, two stages in the development of the eggs present at any time in the mature ovary, namely, (*a*) undeveloped oogonia and young oocytes, with a single nucleolus and very inconspicuous cytoplasm, and, (*b*) reserve fund eggs, about 70*u*-100*u* in diameter, with large nucleus, numerous small nucleoli arranged closely beneath the nuclear membrane, and deeply-staining cytoplasm. At the time of recovery and preparation for spawning, a third stage is present, namely, the current season's crop of active eggs, which arose by the renewal of activity in a certain proportion of the reserve fund eggs.

Wheeler (1924) suggests that the "reserve fund" eggs are regenerated from certain of the follicle cells, which are known to be sister-cells of the oocytes. From a careful examination of my material, this is possible and probable. But if my view is correct, and not based on faulty reasoning, there is no need to look for a great formation of new oocytes at the close of a spawning season. The numbers of new eggs added to the reserve fund are very easily covered by the reserve of undeveloped oocytes and oogonia which are always to be seen, even in very old fish, lying beneath the ovigerous lamellae, in the spent ovary.

Since the annual liberation of ripe ova is the dominant periodic function of the ovary, the change from the first stage to the second stage probably takes one season, and the change from the second to the third and final stage, one season also, but there is no reason to believe that an oocyte, which has been added to the reserve fund in one season, necessarily matures in the following season.

SECTION D.

ON THE SEASONAL CHANGES IN THE CONDITION OF THE HAKE.

The technique followed in the collection of the data on which this section is based has already been described in the Introduction. For each fish, the length, weight of gonad, weight of liver, and weight of gutted fish (hereafter referred to as the "flesh") are available. In the treatment of the data the individual weights are not considered; the conclusions are based on the mean length and weight of the fish, as grouped into 10 cm. groups. These groups are quite arbitrary; the fish in each biological sub-division of the hake are divided up into fish of 50 to 59 cms., 60-69 cms. and so on. The fish were measured to the "centimetre below." In Section A, reasons have been given for believing that the mean weights, where the mean is based on a considerable number of observations, are reasonably accurately determined. The data are set out in Tables VIA and VIB.

Where a very large number of fish are included in a 10 cm. group, the mean length of these fish is naturally very near the mid-point of the group. In the higher centimetre lengths, where data become more scanty, the mean length may vary considerably from this half-way point, and may also vary from sample to sample. But discrepancies in the mean weight, due to this, may be minimised by using the "coefficient of condition" k, and, in the following pages, this is done when the various length-categories of hake are compared with one another.

The "coefficient of condition" is the product of the mean weight of the organ under consideration, divided by the cube of the mean length of the fish of the group, multiplied by 100, to avoid unwieldy groups of decimal ciphers; thus

$$k = \frac{100w.}{l^3}$$

where w = mean weight, and l = mean length.

As the following pages will show, k is approximately a constant, at all lengths, at the time of exhaustion in the fish, when the supplies of mobile reserve material are spent.

As stated in the Introduction, the fish used for this investigation were not unselected, but selected so as to give as good a sample as possible at each length-group. An obvious objection is, that by this artificial grouping of the data in 10 cm. groups, and following the seasonal changes of condition in each group, no account is taken of the growth which is taking place in the interval; one is not dealing with the same fish at the end of the series of observations as one dealt with at the beginning, since the bulk of the original fish may, by growth, have moved up into a higher length-category. In practice, it would be quite impossible to be sure that one was sampling the same shoal of fish throughout the year; in any case, abundant proof will be found, in Table VIA, that the seasonal changes in condition are identical in nature, though not, of course, in magnitude, at all length-categories of the same biological sub-division of the hake. The present method of grouping the data shows these changes very clearly, and, in interpreting them, it is only necessary to bear in mind the fact that, by an artificial device, growth has been neglected, and that, therefore, where a loss of weight is shown in the following pages, this is a loss of weight relative to length. The method of grouping each biological sub-class into 10 cm. categories has this very considerable advantage, that the successive length categories may be used to check one another, and thus give one more confidence in the deductions to be drawn from them.

There is often a wide variation in the weights on which any mean is based. In the case of the roe, this may be seen at once by an inspection of Table X in the Appendix. The mean weights discussed must not, therefore, be taken to mean that the fish sampled had gonads, liver and flesh all near the calculated mean for the group. The seasonal shift in the mean weights, however, does accurately reflect the seasonal change in the general condition of the hake shoals. An example of this has been seen in Figures 1 and 2, where the condition of the gonads, based on a naked-eye inspection and classification into arbitrary maturity stages, is in excellent agreement with the changes in mean weight. The mean weights, therefore, are not "statistical figments," but have a real biological significance.

In this Section, the data will be considered under the following heads :—

(1) The seasonal change of condition in the mature male.
(2) The seasonal change of condition in the mature female.
(3) The seasonal changes of condition in the mature male and female compared.
(4) The seasonal changes of condition in adolescent and immature female hake.
(5) The seasonal changes of condition in immature, adolescent, and mature female hake compared.
(6) Other factors associated with the seasonal change in condition of the hake.
(7) The hake in the Norwegian Deep, Skagerrak, and Firth of Clyde.

D.—(1) The Seasonal Change of Condition in the Mature Male.

The length-category 70-79 cms. will be taken throughout this section as typical of mature males. It is usually adequately sampled and, owing to the large size of the fish, the seasonal changes in the mean weight of the fish and its organs are great enough to discount experimental error.

In Figure 7 is drawn the curve for seasonal variation in mean weight of the testis in males of 70-79 cms. The data are taken from Table VIA, and the figure corresponds to Figures 1 and 2, wherein the seasonal variation in mean weight of the ovary in adolescent and mature female hake is shown. No attempt was made, however, in the case of male hake, to distinguish between various arbitrary maturity stages. Birtwistle and Lewis (1925) used Hjort's scale of maturity stages in dealing with male hake but, in my experience, the ripening and exhaustion of the testis is a continuous process allowing of no classification into stages, such as was undertaken in female hake. The seasonal changes in the testis, therefore, must be followed in mean weight alone.

The curve in Figure 7 is very jagged, but the trend is clearly for the mean weight to rise to a maximum in June and July, with a rather more rapid fall to a minimum in the autumn. This conclusion is borne out by the data referring to the remaining length-categories, as may be seen by an inspection of Table VIA.

The data on which Figure 7 is based refer to many widely separated fishing grounds, and it would simplify matters if we could follow the seasonal changes in male hake on a single fishing ground, with a consequent greater probability that we are sampling the same stock or group of hake throughout. A good series of observations are available from the well-known hake grounds "Below the Bull" (see chart in Frontispiece), though it is greatly to be regretted that no samples were taken on this ground between early December and March.

In Figure 8 three curves are drawn. They represent the seasonal variation in mean weight of testis, liver, and flesh (by which is here meant the gutted fish) in (mature) male hake of 70-79 cms. on the Bull grounds. The data are to be found in the Appendix, Table VIA. The mean length of the fish in each sample may be seen by an inspection of the table, but it may be said here that they vary only slightly, and that a correction, applied to eliminate the effect of these variations, has been found to make no significant difference to the picture presented.

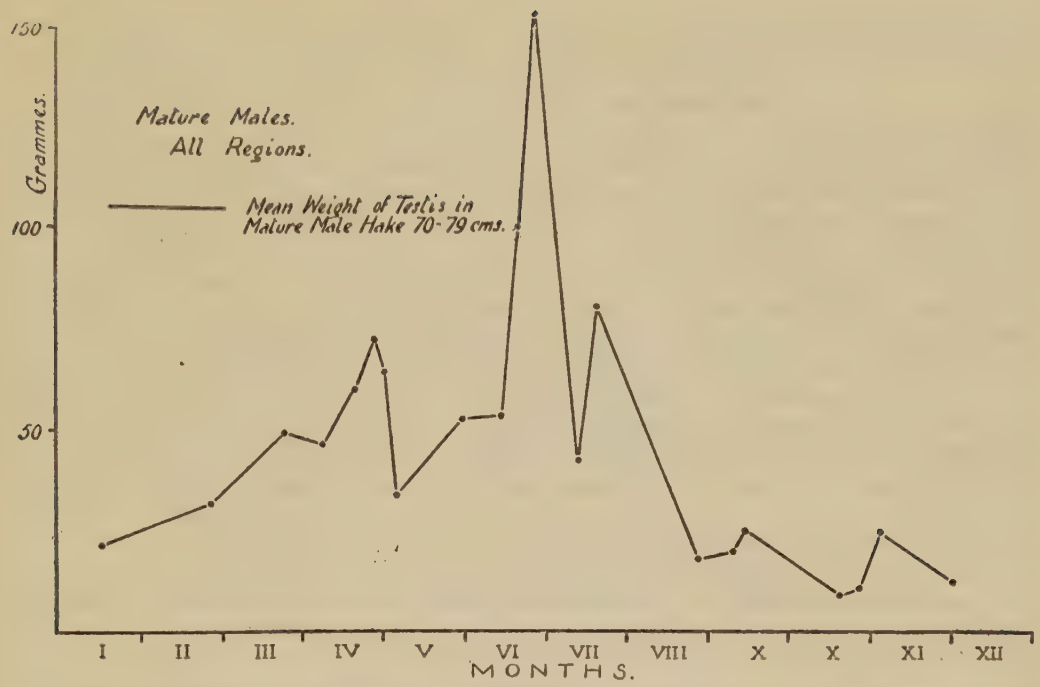

FIGURE 7.—Seasonal changes in mean weight of testis in the 70–79 cms. category. All regions. Data in Appendix, Table VIA.

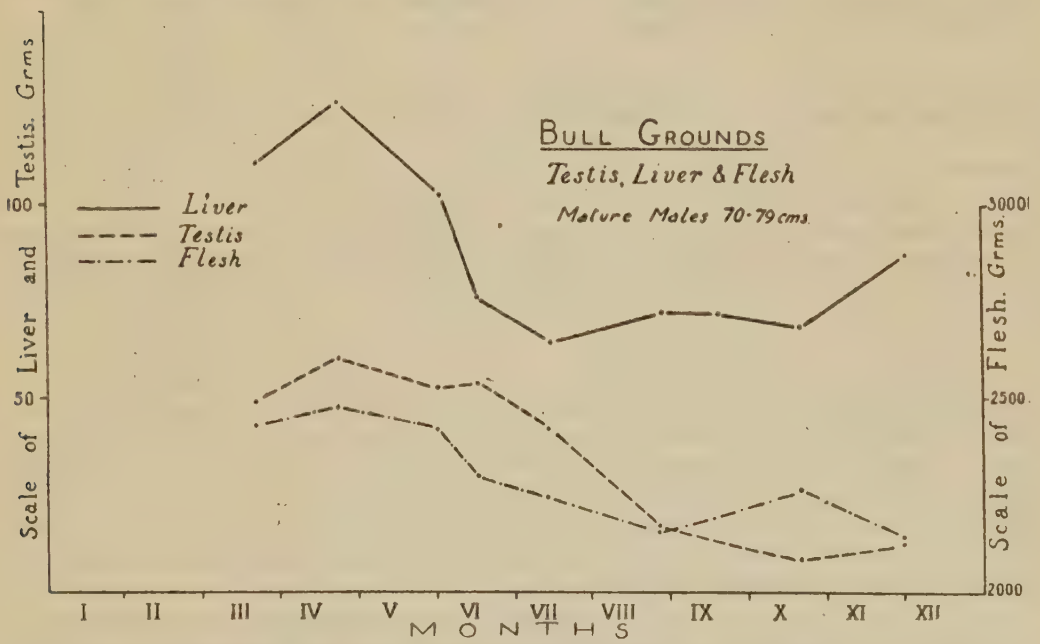

FIGURE 8.—Seasonal changes in mean weight of testis, liver and flesh, in male hake of 70–79 cms. Bull grounds. Data in Appendix, Table VIA.

The curve for the seasonal variation in the mean weight of testis (pecked line, Figure 8) shows a maximum in April, and remains fairly steady (though losing weight slightly) until June. It then loses weight until August, and shows no notable recovery between then and December. Almost the whole of the recovery must be presumed to take place between December and March.

The curves for the liver (continuous line) and flesh (dot-and-dash line) show a . . d general agreement with each other. Both show a maximum in April, followed by a fall until July or August. Between July and December the liver shows a considerable recovery, but the flesh shows a less definite recovery.

To sum up the deductions to be drawn from Figure 8:—testis, liver and flesh are all heavier (relative to the length of the flesh) in the early part of the year than in the later. Liver and, to a less extent, flesh, recover somewhat before December, but the testis does not appear to do so. In the spring, the maxima in all three organs are in April, but the testis appears to remain comparatively heavy somewhat longer than liver and flesh.

These conclusions, based on the data for the length-category 70-79 cms.. may be checked by a consideration of the remaining length-categories. Though there are some discrepancies, these categories agree well with the 70–79 cms. category, so that the curves in Figure 8 may be considered typical of mature males.

Table VIA shows that, as will be readily understood, the seasonal variation in mean weight is much smaller in the smaller hake than in the larger hake, and, in the case of the 50-59 cms. category at least, variations in the mean lengths of the samples may become significant.

But there is a well-marked increase in the amplitude of the seasonal variation in mean weight of testis, liver and flesh, with increase of length. This increase in amplitude may best be examined by using the coefficient " k," using, as the factor " l " in the expression $k = \frac{100w}{l^3}$, the actual mean length of the sample on which the weight " w " is based.

These results are set out in Table VII, page 74.

The difference between the minimum and maximum values of k will give the amplitude of the seasonal variation, reduced to a common basis, in the successive length-categories.

An inspection of the data referring to mature males, in Table VII, will show that in testis, liver and flesh, the increase in the amplitude of the seasonal variation, with increase of length, is of the order of geometrical progression.

At the time of minimum weight, the value of k tends to be a constant, whereas the value of k at the time of maximum mean weight increases from category to category in approximately geometrical progression. Since the seasonal variation is probably mainly connected with the spawning act, this indicates that the metabolic strain on the mature male is a burden which doubles its weight with each 10 cms. increase in length. This, in my opinion, is deeply significant from the point of view of the growth of the male.

A second point is, that the amplitude of the seasonal variation is much greater in the testis than in the liver, and in the liver than in the flesh. The obvious reason is that there is a far larger proportion of permanent tissue in the gutted fish than in the liver, and in the liver than in the testis. The testis becomes reduced, at the time of greatest exhaustion, to the connective tissue membranes and a relatively small amount of spermatocytes, whereas in the liver there is the permanent liver tissue, and in the gutted fish the connective tissues, bones, spinal cord, finrays, skin, muscles, etc., which are all permanent tissues, in whose aggregate weight no great fluctuations are to be expected. Nevertheless, as Figure 8 and Table VII show, there is some withdrawal of material in the summer, and a replenishment in winter and spring. Hughes (1891-2) shows that there is 0·03 per cent. of fat in the flesh of the hake.

D (2).—The Seasonal Change in Condition of the Mature Female.

In Figure 1 a curve has been drawn, which represents the seasonal changes in mean weight of the ovary of mature hake of 80-89 cms. The irregularities in the

curve are mainly due to the fact that extreme depths were included in the grounds sampled,* especially during the exploratory voyages of the *Florence Brierley* in the spring of 1927 (Hickling, 1928). The very high July value is due to a sample from 30 fathoms in the Firth of Clyde. This sample had a high proportion of females in the "running" condition, and there is a sudden very great increase in the bulk of the ovary at the time of actual spawning, owing to the absorption of water by the eggs (see, for example, Milroy, 1897).

The curve for mean weight of ovary rises from January to a maximum in June and July, after which there is a rather more rapid loss in weight until October. There appears to be some recovery by early December. These results are confirmed by an inspection of the curves for the proportion of ovaries in the penultimate condition of ripeness, and by the landings of ripe roes by commercial trawlers (Figure 1).

The seasonal changes in mature females will now be followed in the series of samples from the grounds "Below the Bull" (see chart in Frontispiece). The length-category 80-89 cms. will be used as typical of mature females, just as the length-category 70-79 cms. was used as typical of mature males. An inspection of the data in Table VIA shows that the length-category 80-89 cms. represents fairly the bulk of the data, and is usually adequately sampled.

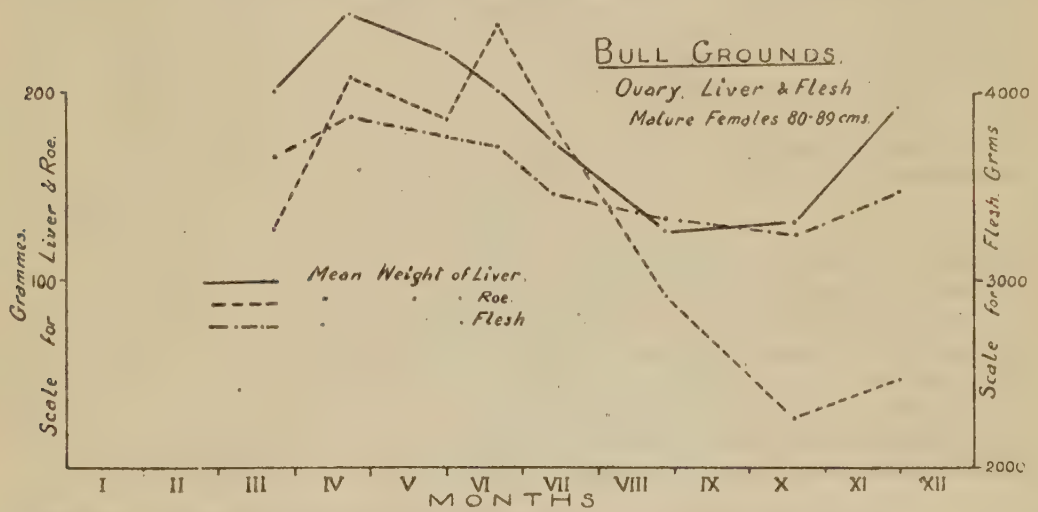

FIGURE 9.—Seasonal changes in mean weight of ovary, liver and flesh, in mature female hake of 80–89 cms. Bull grounds. Data in Appendix, Table VIA.

In Figure 9 three curves are drawn, representing the seasonal changes in mean weight of roe and liver (scale to the left) and of the flesh (scale to the right) of mature females of 80-89 cms. on the Bull grounds.

Disregarding the drop in the curve for mean weight of ovary between April and early June (in which the 80-89 cms. category is anomalous as compared with the 70-79 and 90-99 cms. categories, Appendix, Table VIA), the ovary is seen to increase in mean weight from March to a maximum in June. There is then a loss of weight to a minimum in October, and, between then and December a slight recovery.

The curves for mean weight of liver and flesh show a very close agreement. In March they have a comparatively high value, which increases to a maximum in April. Both then lose weight, relative to length, until the autumn, having their minimum mean weight in August (liver) and October (flesh). Between October and early December, both recover to a value not far short of the March value.

An interesting point is, that liver and flesh make an early and rapid recovery from exhaustion, the ovary a late and slow recovery.

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* *See* Section D (6), page 44.

To sum up the deductions to be drawn from Figure 9, ovary, liver and flesh are relatively heavier (relative to the length of the fish) in the early part of the year than the later part. Liver and flesh show a good recovery between their minimum in October, and early December, but the ovary shows only a slight recovery. In the spring, the maximum mean weight in liver and flesh is reached in April, but the ovary, while reaching a high value in April, reaches its maximum in June, thus somewhat later than the liver and flesh. These conclusions are confirmed by an inspection of the data for the 70-79, 90-99 and 100-109 cms. categories, in Table VIA.

As in the case of the males, in the preceding section, the amplitude of the seasonal fluctuation in mean weight of the mature female hake and its organs may be compared, in the different length-categories, by using the coefficient k. The data are to be found in Table VII.

The "difference" columns in Table VII show that, in the ovary and liver, the length-category 70-79 cms. has a greater amplitude of seasonal variation than the 80-89 cms. category. This is not apparent, however, in the case of the flesh. It may be that the first full ripening of the roes, using the material accumulated during the adolescent stage, is more vigorous than those immediately following it. In the 100-109 cms. category, there is either actually a decline in the amplitude of seasonal variation (liver and flesh) or a decline in the rate of increase, with increase of length (ovary) as compared with the 90-99 cms. category. This probably indicates a slackening off of sexual activity in the very old females, such as Belloc (1923) has observed, and as I have mentioned in Parts I and II of this Natural History (1927).

It is clear, therefore, that though there is a tendency towards an increase in the amplitude of the seasonal variation in mean weight of the gutted fish and its organs, with increase of length, it is irregular, and shows no such definite tendencies as the corresponding data for males (Table VII).

It will also be noticed that the value of k (ovary) at minimum shows an increasingly rapid rise with increase of length. This might have been expected, for it is easy to see that the ovaries in older females have enormously thick fleshy walls; probably after each spawning the muscle and connective tissue in the walls thicken. The values of k (liver) at minimum also tend to show an increase, with increase in length; this is probably due to an increase in the permanent tissues of the liver with the normal growth of that organ. The *seasonal* variations in mean weight, of course, are due to differences in the *content* of the liver cells. On the other hand, the values of k (flesh) at minimum show a tendency to decrease with increase in length.

D(3). The Seasonal Changes of Condition in the mature male and female compared.

Fundamental metabolism in a fish has been exhaustively studied by Noel Paton and his collaborators (1898). In the Salmon, not only the changes in mean weight, but the chemical changes were studied, and thus both quantitative and qualitative information as to the changes taking place during the maturation of the gonads, and the migration up the rivers, was obtained. Paton's paper is so suggestive, in the light of the purely quantitative experiments which form the basis of this paper, that it may be worth while summarising the more important points in the fundamental metabolism of the Salmon, especially since Paton's paper is out of print and copies are rare.

It is obvious that material is added to the tissues of a fish from food digested in the alimentary canal, and that material is taken from the tissues in the form of the by-products of chemical changes involved in the expenditure of energy and also, in sexually mature fish, in the form of the finished sexual products, eggs or spermatozoa. But the rate of addition or loss of material varies very widely according to seasonal and other factors. On the credit side, the rate of feeding varies, and the

quantity and quality of the food varies ; on the debit side, the fish's expenditure of energy must vary with the intensity of pursuit of prey, and with the rapidity and duration of other migrations, such as spawning migrations ; and finally, of course, the loss of material becomes very great in mature fish which are shedding their sexual products. Generally speaking, the great loss due to extensive migration, or heavy spawning, or both, is provided for by the storage of surplus material during some other part of the year, when the supply of food available to the fish, and its ability to assimilate that food, is greatly in excess of the fish's immediate needs at that time.

In the Salmon, Paton shows that there is no feeding during the fish's passage into the river estuaries and up to the headwaters of the streams, but that there is a supply of stored material in the organs of the fish, especially the muscle, amply sufficient, not only to cover the needs of the developing genitalia, but to leave a large surplus for the production of energy. Indeed, the so-called " winter salmon " can remain for a whole year in freshwater streams without feeding, and yet have enough stored material in their tissues to produce their crop of eggs or sperm when the time comes round. The whole of this material is obtained from that stored up, chiefly in the muscles, during the salmon's life in the sea.

Paton finds that the weight of muscle in salmon reaching the estuaries in October and November shows a marked diminution as compared with fish coming earlier in the year, and concludes that " the supply of food (in the sea) is insufficient to yield the material necessary for the rapidly growing genital glands, and that therefore the solids of the muscle have to be drawn upon." The loss in weight is therefore due to loss of " solids " from the muscle tissues Paton draws up a " balance sheet " of loss from the muscle and gain by the genitalia, and shows that the loss of solids by the flesh is twice as great as the gain of solids by the ovaries, and nearly 22 times as great as the gain by the testis, so that there is a vast surplus of " solids " available for energy production in both sexes, but especially in the male.

These changes in weight have been correlated with changes in chemical composition. The salmon coming to the estuaries in October and November have only three-quarters of the amount of fat they had at the beginning of the season, while, in the same months there is an eightfold increase in the fat content of the ovaries. In the males, the accumulation of fat in the muscles is as great as in the females, and is used up to quite as great extent. On the other hand, the accumulation of fat in the testis is trifling in amount, and " the conclusion is reached that, in the male, the utilisation of fat as a source of energy is much greater than in the female."

Paton shows that there is no important accumulation of stored fat in the liver, but that considerable quantities of fat may be stored among the viscera, chiefly around the pyloric appendages. This is the first fat to be drawn upon, and is used up more rapidly than the muscle fat.

The weight of solids in spent salmon is about the same as in fish with fully ripe genitalia, but very markedly less than in fish in which the genitalia are still undergoing development. Owing to an increase in the water content of the tissues, however, there is little loss of actual weight in spent salmon, as compared with the unspawned fish ; " it is this increase in the percentage of water in the flesh which maintains the weight of the fish, although the solids, as a whole, have diminished."

The proteids do not disappear to anything like the same extent or at the same rate as the fats, and it is from the fats that the energy for muscular work is chiefly procured. Quite early in the season, while the ovaries are growing slowly, the proteids disappearing from the muscle are more than sufficient to meet the needs of these structures, while, later in the year, when the growth of the ovaries is going on more rapidly, all the proteid disappearing from the muscle is transported to, and used in them. In the male, the amount of muscle proteid disappearing from the muscle is so much more than is sufficient for the requirements of the growing testis

very much larger surplus is available for muscular work in the male, than in the female.

Of the fats and proteids lost from the muscles, in the female 12 per cent. of the fats and 23 per cent of the proteids goes to the ovaries, the rest being available for energy; while, in the male, about 5 per cent. of the fats and 14 per cent. of the proteids go to the testis, the rest being available for energy.

In the female, 20 per cent. of the available energy is derived from the proteids, whereas, only 9 per cent. of the available energy is derived from this source in the male.

Greene (1913) finds that fat is the prominent and immediate source of energy expended by the salmon during the spawning migration. The fat reaches its maximum at the time of the ending of the feeding stage, and is primarily stored in the muscle.

Bruce (1924) finds, in his analyses of herring tissues, that "the metabolic demands of the growing gonads are met, in the first instance, by the fatty reserves of the liver; the muscular tissue is not depleted until shortly before spawning occurs."

Bull (1928) finds that no significant changes occur in the composition of the muscle substance of the whiting, either throughout the year, or with increasing age, or during ripening of the gonads. The liver, however, undergoes great change in composition. He concludes (albeit on inadequate data) that there is no correlation between the changes in liver and muscle.

This paper deals only with seasonal changes in mean weight of the hake and its organs. No chemical analyses have been attempted. But the seasonal changes in mean weight of gonad, liver and flesh are strikingly regular, and most suggestive. By comparison with Paton's work on the salmon, one can safely assume that the greater part of the weight gained or lost, relative to length, by the gutted fish and its organs, during the season, is due to withdrawal or addition of "solids," and in true index of the hake's fundamental metabolism. However, in interpreting weight as condition, in this way, it is possible that, at the time of exhaustion, the mean weight of the fish may be maintained by the addition of water to the tissues, as Paton found in the salmon. The actual withdrawal of solids from the fish may be even greater than the mean weight suggests.

If, therefore, it is permissible to interpret loss of weight as loss of "solids," the hake resembles the herring (Bruce) in that both liver and flesh are drawn upon for reserve materials (as shown in Sections D(1) and D(2)) rather than the Salmon, in which mainly the flesh, or the Whiting, in which mainly the liver, is drawn upon. The liver of hake, at the time of its maximum mean weight, is obviously very rich in fat, but the muscle, according to Hughes (1891-2) contains only 0·03 per cent. of fat. He does not state, however, at what time of the year his sample was collected. Possibly, the liver supplies the bulk of the fat in the hake, the flesh the bulk of the proteid, but this must remain only a speculation.

In Sections D(1) and D(2) the seasonal changes in mean weight of gonad, liver and flesh, in males and females respectively, on a single fishing ground, have been discussed. The fundamental metabolism of the mature male will now be compared with that of the mature female, taking the length category 70-79 cms. as typical of the mature male, and 80-89 cms. as typical of the mature female. Since the males and females which are to be compared are not of the same length, the actual weights of the organs of these fish will not be used. Instead, the mean increase in weight of each sample over the minimum will be considered as a percentage of the total seasonal range of variation. At maximum mean weight the percentage will be 100 per cent., at minimum mean weight 0 per cent. Thus we may compare the fundamental metabolism of male and female hake directly, without complications due to a different length. The data are to be found in the Appendix, Table VIII.

Since liver and flesh undergo closely similar changes in mean weight, these two weights are added together, and in Figure 10 four curves are drawn, representing

the percentage of the total range of seasonal variation, in the series of samples from the Bull grounds, in testis, ovary, and liver and flesh of both male and female hake.

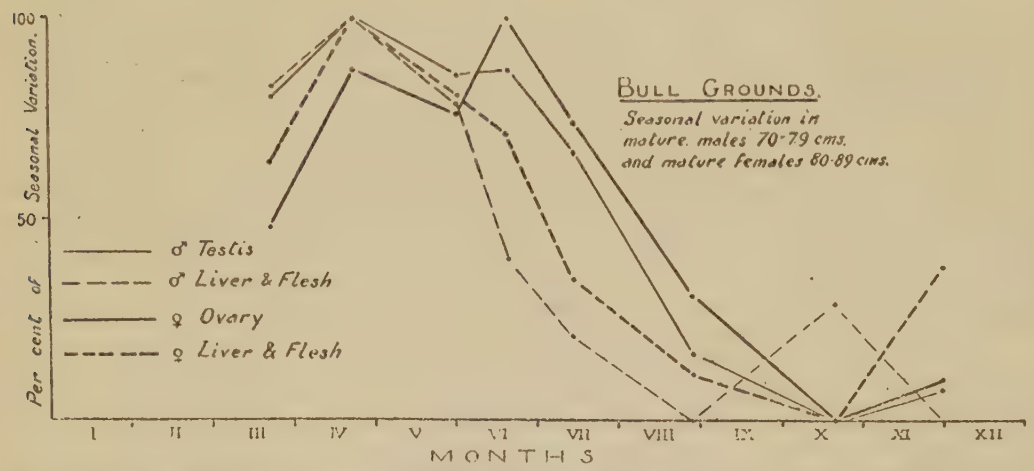

FIGURE 10.—Seasonal changes in condition of mature males and mature females compared. Bull grounds. (Mature males, 70–79 cms., mature females, 80–89 cms.) Data in Appendix, Table VIII, calculated from Table VIA.

Figure 10 shows that the seasonal variations in mean weight of testis and ovary are, in the main, very similar. Both have their minimum mean weight in October, and both recover, to some extent, by December. Allowing for the gap in the data, both testis and ovary recover rapidly between December and March, the testis apparently doing so more rapidly than the ovary, for in March, the testis has recovered 80 per cent. of the year's increase, and reaches the maximum in April, whereas the ovary has recovered only 48 per cent. of the year's increase by March, and reaches the maximum in June. Between April and June both testis and ovary remain at approximately the same level, the testis losing weight slightly, the ovary gaining weight slightly. In July and August both testis and ovary lose weight rapidly. The months from April to July must be considered the time of most effective spawning on the Bull grounds, on the evidence offered by Figure 10, though, as Table IV shows, actually spawning hake were found on these grounds in March. In Section B, it was concluded, from a consideration of the mean weight of the roe from all grounds, the proportion of ovaries in the penultimate condition of ripeness, and the commercial landings of roes, that the spawning season for hake had its height in July. In my 1927 paper, I recorded the finding of spawning hake, in 1925, from March to July, in the South-Western area.

The length of the spawning season in the male is much less easily defined than in the female, for, during the greater part of the year, males may be found whose testes contain milt. It appears from Figure 10, that the testes ripen earlier than the ovaries, so that the spawning season is longer in the male than in the female hake. Graham (1924) writes, of the Cod, " the males are ready to spawn for a much longer time both before and after the females." Hodgson (1925) says of the herring, " the numerous instances of males ripening before the females would suggest that this is the normal behaviour of the fish." Masterman (1911) says, of the Plaice, " the proportion of ripe fish becomes greatest, for males in February, and for females, in March." The hake, therefore, seems to fall into line with these other important fish in the greater length of the spawning season in the male. This is probably a provision to secure the fertilisation of all the eggs spawned.

The spawning season in hake is remarkably constant from year to year, and is more or less simultaneous over a wide geographical range. In Figure 1, the plotted points both for percentage of ripe roes, and for mean weight of ovary, and in

Figure 7, the plotted points for mean weight of testis, though based on material collected over a wide range both of time and geographical area, fall fairly evenly about a mean curve, and one may conclude that the annual ripening of the gonads is sufficiently constant to hold over time and space differences in the data. In Part I of this Natural History (1927) it was concluded that "generally speaking, the time of best fishing is later in the year as the latitude of the region lies further north." There seems to be a two months' lag in the time of best fishing as between the South-Western area and the West of Scotland, but there appears to be room for such a lag in the data on which Figures 1 and 7 are based.

Further confirmation of the constancy of the spawning season may be found by considering the landings of hake roes. In Table IXA in the Appendix are set out the monthly landings of roes at Cardiff, 1921-1929. Cardiff has been chosen because the Cardiff fleet of trawlers specialises in the hake, and we may be far more certain in the case of Cardiff, than of any other port, that the vast majority of roes landed are hake roes. Table IXA shows that, in four years out of nine, the highest landings of roes occurred in May, in five years out of nine, in June.

In Part I of this Natural History, it is shown that there are two maxima in the annual course of the hake fishery (shown clearly in the data for catch in unit time, Figures 3, 4, 5), namely, a maximum in the early summer, and a secondary maximum in midwinter. The summer maximum clearly agrees with the maximum in the landings of roes, and confirms the opinion, based on general observation, that the high catches at this time of the year are due to the spawning concentrations. The midwinter maximum, which, I have suggested, is, in part at least, a feeding concentration, is quite unreflected in the landings of roes. But since the commercially valuable roes correspond, as Figure 1 shows, to the roes in the penultimate condition of ripening, the time of maximum spawning, and therefore of maximum landings of big and medium hake, must tend to take place shortly after the highest landings of roes, and an inspection of Table IXA shows that this is the case. In six of the nine years, 1921-9, the maximum landings of big and medium hake have occurred in the same month, or in the month immediately following, the month of maximum landings of roes. Since the Cardiff fleet fishes in the South-Western area and to the West of Ireland, the information gathered both from weighing experiments and from the commercial statistics points to May-July as the time of maximum spawning in these areas.

Returning to Figure 10, it is seen that liver and flesh, in both males and females, have their maximum in April, and a minimum in August and early December (males) and October (females). I do not consider the October recovery shown by the liver and flesh of the males as significant, and both sexes may be regarded as having their liver and flesh at a minimum in about October. From April to October, therefore, liver and flesh lose material (relative to length), and, considering that the spawning season on the Bull grounds is from April to July, it appears that the material lost from the liver and flesh is mainly transferred to the gonads, at such a rate that the weight of the liver and flesh falls off before that of the gonads. The seasonal rhythm in the mean weight of liver and flesh is therefore probably induced by the seasonal rhythm in the gonads.

By early December, liver and flesh in the male show no definite recovery, whereas in the female, 37 per cent. of the year's increase has been recovered. But, during the months for which no data are available, *i.e.*, early December to March, the liver and flesh in the male recover 83 per cent. of the year's increase, the testis 73 per cent., while the liver and flesh of the female recover 27 per cent., the ovary 38 per cent. of the year's increase.

In the female, therefore, there is a rapid recovery in liver and flesh before the roe shows any significant recovery, and then there follow some months in which the rate of increase in liver and flesh is much slowed down, while that of the ovary increases. In the final stages of the ripening of the roe, the liver and flesh actually

lose weight. In the male, on the other hand, there is no earlier recovery in liver and flesh before the recovery of the testis, and testis and liver and flesh gain weight at about the same rate.

These differences between the sexes are almost certainly due to the much greater mass of the sexual products of the female. This requires an earlier recovery in liver and flesh, and accounts for the slowing down in the rate of recovery in liver and flesh, when the roe commences its rapid recovery.

In the Salmon, which was the subject of Paton's work, no food is taken during the maturation of the gonads in freshwater, and the changes in mean weight observed in the organs of the salmon, at this time, may be regarded as due to a transference of material, either for consumption to provide energy, or from the muscles, etc., to the developing gonad. In the hake, on the other hand, while the rate of feeding falls off considerably as the gonads ripen, as shown in Part II. of this series, it never ceases, except probably during the actual spawning act. There is thus a continuous inflow of food material. During part of the year, between October and April, when feeding is vigorous, the balance of income of material over expenditure is heavily on the credit side, and the surplus is stored up in liver and flesh, as well as being used for growth. This surplus is over and above the material required for the production of energy, and for the earlier stages of recovery in the gonads. But when spawning commences, the income of material is insufficient to cover the loss due to the emission of the sexual products, and reserves must be withdrawn from the liver and flesh. The material so withdrawn must be assumed to pass to the gonad, and be lost to the exterior in the form of the sexual products. Russell (1914) concludes, from his study of the seasonal variation in condition of the cleaned haddock, that there is a transference of material from the somatic tissues to the gonad, prior to spawning.

There is good reason to believe that, at the time of greatest exhaustion, liver and flesh are stripped of mobile reserve material. The co-efficient k at that time tends to be a constant, as Table VII. shows, and liver and flesh then behave like other organs, such as the alimentary canal, which do not store up reserve material. But the commercial landings of hake livers are more convincing in showing that the liver, at least, is stripped of reserve oil. As in the case of the roe, and for the same reason, the landings of livers at Cardiff will be discussed. The data are to be found in the Appendix, Table IXA.

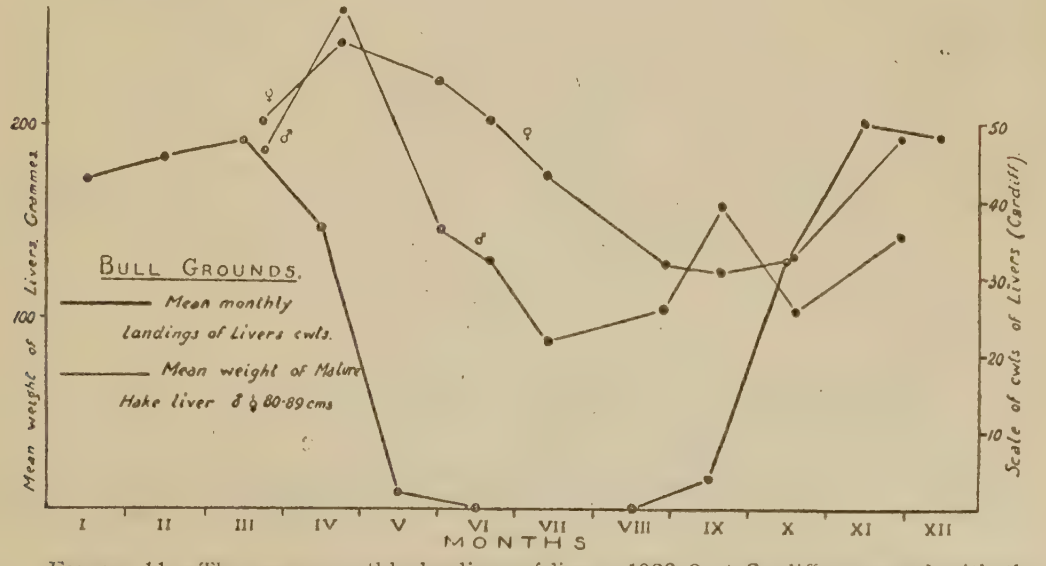

FIGURE 11.—The mean monthly landings of livers, 1923–8 at Cardiff compared with the seasonal changes in mean weight of liver in male and mature female hake, 80–89 cms. Data in Appendix, Tables VIA and IXA.

In Figure 11 three curves are drawn. The thick line shows the mean monthly landings of livers at Cardiff during the years 1923–8 (scale to the right), and the two thin lines show the mean weight of liver in mature males and females of 80–89 cms., as found in my experiments. The three curves are in satisfactory agreement. It is seen that few or no livers are landed from May to September. The reason for this cessation in the landings is probably :—that the by-product factories, which deal with these livers, have found that the liver of the hake, at this time, is so exhausted of oil as to be not worth working up. This conclusion, applied to the curves for seasonal variation in mean weight of the liver, implies that the loss of weight in the liver of male and female hake between May and August is mainly due to an exhaustion of reserve oil. Similarly, the recovery between October and early December is due, probably, to a restocking of the exhausted liver with reserve oil.

It is interesting to note that there is a " lag " between the curves for mean weight of liver and the commercial landings of livers. The latter fall to zero before the mean weights show a serious loss, and commence their rise to a maximum before the mean weights show a recovery. This may mean that the oil is the first product of the liver to be withdrawn in quantity, and certainly agrees with the finding, described in Section B, that oil droplets are the first reserve materials to appear in the ripening eggs.

We have seen, in Sections D(1) and D(2) that the liver and flesh show closely similar changes in mean weight, so that the flesh has its maximum and minimum mean weight at much the same time as the liver. One might expect, therefore, that the gutted fish will be in its best condition between December and April, and in poor condition between June and August, and that this difference in condition might be reflected in the price paid for it.

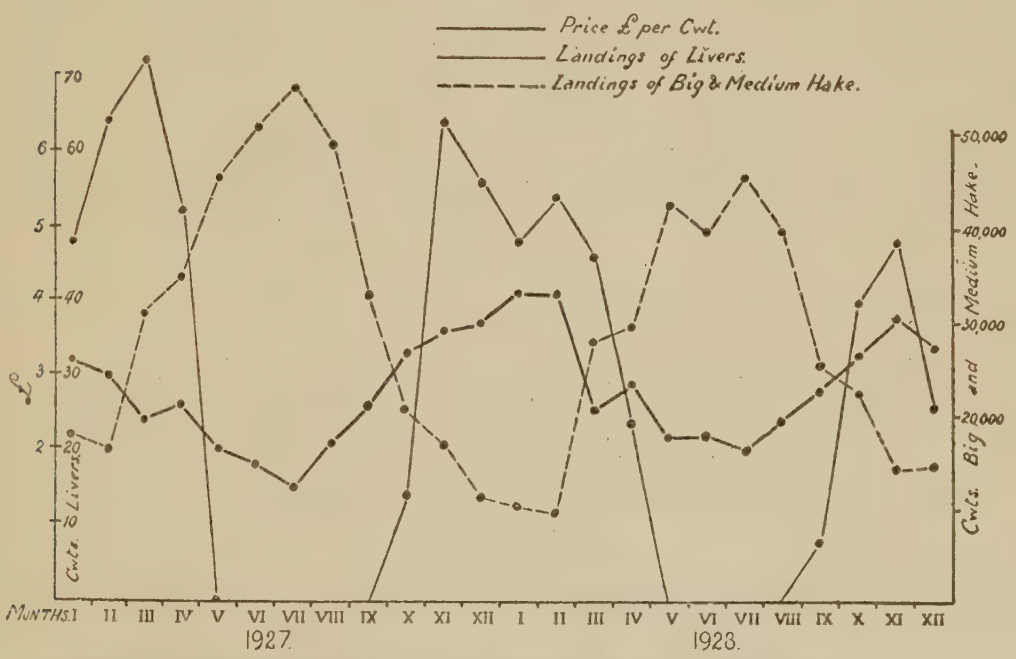

FIGURE 12.—Monthly landings of big and medium hake, all ports, 1927-8, price per cwt. of big and medium hake, all ports, 1927–8, and landings of livers at Cardiff, 1927–8. Data in Appendix, Tables IXA and IXB.

In Figure 12 three curves are drawn. They represent, for the years 1927 and 1928, the monthly landings of big and medium hake (pecked line, scale to the right), the monthly landings of livers (thin line, scale to the left), and the price per cwt. of

big and medium hake (thick line, scale to the left). The data are to be found in the Appendix, Table IXb.

The price per cwt. paid for big and medium hake shows a good correlation with the landings of livers; the price paid is highest at the time when livers are being landed, that is, when the liver, and therefore the flesh, is in good condition. But it is clear that there is a very good inverse correlation between the landings of big and medium hake and the price paid; this is in accordance with the law of supply and demand, since, when the landings of hake are low, the price will tend to be high, and *vice versa*. Moreover, fish are less valuable in the summer because they do not keep so well and because people then eat less fish and more fruit. These factors mask any effect the quality of the fish might have upon the price paid for it.

In Figure 13 the monthly landings of livers, roes and of big and medium hake at Cardiff in 1926, 1927 and 1928 are shown. The data are from Table IXa. in the Appendix. It will be seen that the livers reach their maximum first, that the roes commence to rise before there is any serious decline in the quantity of the livers, that the maximum landings of roes occur at the time when no livers are being landed, and, finally, that the maximum landings of big and medium hake occur shortly after the maximum landings of roes. The succession of the maxima in the order liver, roe, and big and medium hake, is perfectly understandable from a consideration of the results of my observations, and it is interesting to find that my small-scale weighing experiments can offer an explanation of some of the seasonal changes in the hake-fishery and its products.

Curiously enough, although the female hake produces a vastly greater bulk of eggs than the male produces of sperm, as the values of k (testis) and k (ovary) in Table VII show, the reserves of the male appear to become exhausted as quickly as those of the female. It may be calculated, from Table VIa, that, to produce 52 grams of sperm, liver and flesh lose 377 grams, a rate of 7·3 grams per gram of sperm, whereas, the female loses 761 grams of material to produce 208 grams of unripe eggs, or 3·7 grams per gram of eggs. This recalls Paton's finding that " the loss of solids by the flesh (in Salmon) is twice as great as the gain by the ovaries, and nearly 22 times as great as the gain by the testis, so that, in both sexes, there is a vast surplus of ' solids ' available for energy production in both sexes, but especially in the male."

D(4). The Seasonal Change of Condition in Adolescent and Immature Female Hake.

In Figure 2 has been drawn a curve representing the seasonal changes in mean weight of the roe in adolescent females of 70–79 cms. This length-category will be used throughout this section as representative of adolescent females, and the data for other length-categories may be found in Table VIa. It may be said, however, that the other length-categories confirm, in the main, the conclusions derived from a consideration of the 70–79 cms. category.

The curve in Figure 2, though irregular, points to an increase in mean weight of the roe in adolescent females from January to a maximum in about June, followed by a decrease to a minimum in the autumn. In Section B, it has already been pointed out that this curve for mean weight is in very close agreement with that for percentage of adolescent ovaries in the " advanced " condition, and that the curves foreshadow the course of events in the fully mature ovary.

The data on which Figure 2 is based were collected from a wide range of fishing grounds, and the seasonal change of condition in the adolescent female will now be followed in the series of samples referring to the fishing grounds " Below the Bull," taking the 70–79 cms. category as typical of the class.

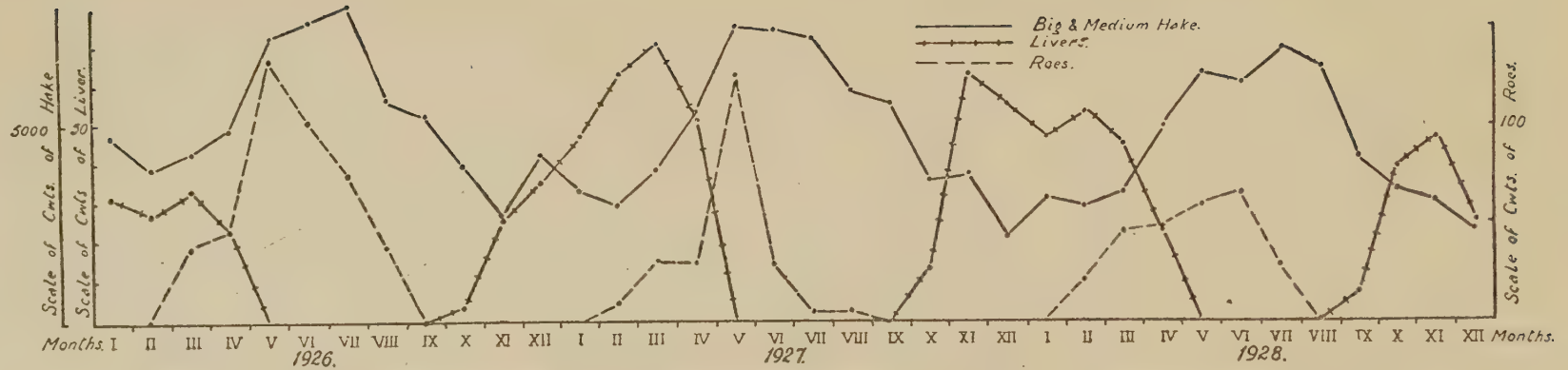
Big & Medium Hake.
Livers.
Roes.
Scale of Cwts. of Hake
Scale of Cwts of Liver.
Scale of Cwts. of Roes.
5000
50
100
Months. I II III IV V VI VII VIII IX X XI XII I II III IV V VI VII VIII IX X XI XII I II III IV V VI VII VIII IX X XI XII Months.
1926.
1927.
1928.

FIGURE 13.—Monthly landings of livers, roes, and big and medium hake at Cardiff, 1926–8. Data in Appendix, Table IXA.

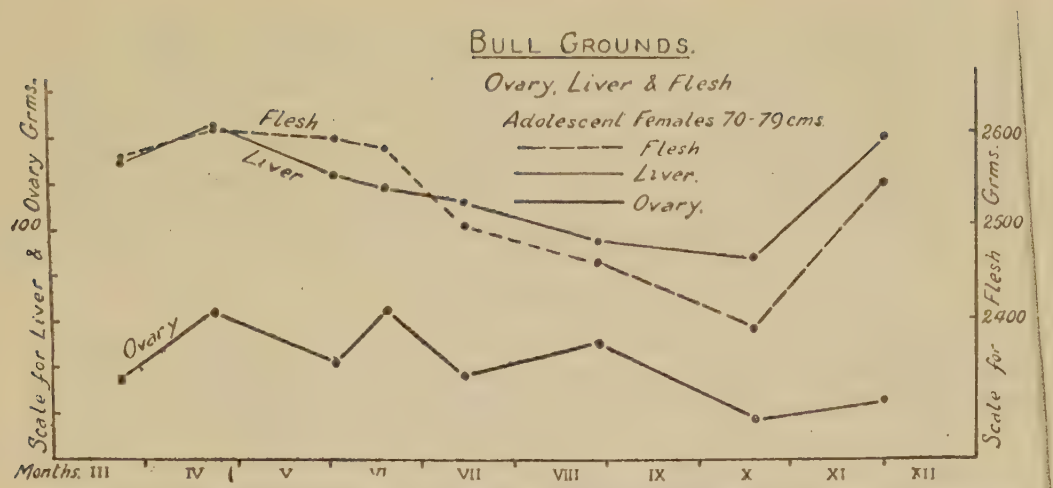

FIGURE 14.—Seasonal changes in mean weight of ovary, liver and flesh in adolescent females, 70–79 cms. Bull grounds. Data in Appendix, Table VIA.

The three curves in Figure 14 represent the seasonal changes in mean weight of the roe, liver and flesh in adolescent female hake, on the Bull grounds. The curve for mean weight of roe shows a tendency to be higher in the early part of the year than in the later part of the year, but is very irregular. There is a good agreement between the curves for mean weight of liver and mean weight of flesh. Both reach a maximum in April, and then decline to a minimum in October. There is a considerable recovery by December.

The amplitude of the seasonal change in condition in the successive length-categories of adolescent females will now be considered, and adolescent females will be compared with mature females. This may most conveniently be done by using the coefficient of condition, k; the data are set out in Table VII.

The value of k (ovary) at minimum is a constant in the three length-categories of adolescent females; at maximum it increases from the 60–69 to the 70–79 cms. category, and then decreases in the 80–89 cms. category. When the adolescent ovaries are compared with the mature ovaries, it is seen that, in the 70–79 and 80–89 cms. categories, there is very little difference between the two classes at the time of minimum mean weight. But the value of k (ovary) at maximum mean weight is about three times as great in mature as in adolescent females.

The value of k (liver), in the adolescent female, at the time of minimum mean weight, is less in the 60–69 cms. category than in the 70–79 and 80–89 cms. category, and the same is true of the values at maximum mean weight. The amplitude of the seasonal variation is much the same in all three categories. The value of k (liver) at minimum mean weight, for the livers of adolescent females, is about the same as that of mature females, as might be expected in fish of the same size whose livers have both, apparently, been stripped of reserve material. But the amplitude in seasonal variation is 55 per cent greater in mature than in adolescent females.

The value of k (flesh), in the adolescent female, at the time of minimum mean weight, is equal in the 60–69 cms. and 80–89 cms. category, but somewhat higher in the 70–79 cms. category. At maximum, however, the values of k are very similar in all three categories, and there is no significant change in the amplitude of the seasonal variation in condition of the flesh with increase of length. As compared with mature females, the value of k (flesh) at minimum shows no significant difference, but the value of k at maximum shows that there is a 43 per cent. increase in amplitude in mature over adolescent females.

In both liver and flesh, therefore, the seasonal variation in condition, which starts at about the same point in both adolescent and mature females, has about 50 per cent. greater amplitude in mature as compared with adolescent females.

Returning to Figure 14, it is seen that roe, liver and flesh, in the adolescent female, all lose weight between April and October, and, in the 70–79 cms. category, this loss amounts to 316 grams. Now, in a mature female hake, the loss of weight from the roe is due to the spawning of the contained eggs, the loss from the liver and flesh probably to the withdrawal of reserve food material to nourish the gonad. But in the adolescent female there is no loss of material due to spawning, and a total loss, relative to length, of 316 grams, or 11·2 per cent. of the weight at maximum, has to be explained on other grounds than actual spawning.

Immature Females.

As might be expected, the mean weight of the roes of immature female hake shows no significant seasonal variation, such slight variations as appear being probably due to experimental error, since the weights are small. The mean weight of the roes of immature female hake on the Bull grounds were :—

50–59 cms.	Mean length	55·4 cms.	Mean weight	5·50 gms.	k (roe)	·0032
60–69 cms.	,,	,,	64·8 cms.	,,	,,	9·59 gms.	,,	·0035
70–79 cms.	,,	,,	73·7 cms.	,,	,,	14·80	,,	,,	·0037

The value of k (roe) is nearly constant, and is decidedly lower than that of k (roe) in adolescent females, even at minimum.

The difficulty in examining the data for immature females for signs of a seasonal variation in condition arises, firstly, in the fact that the fish are of such a small size (and weight), and the seasonal variation is apparently so small that experimental and sampling errors become significant. The data obtained in the series of cruises to the Bull grounds will be used to examine the seasonal change in condition, and the length-category 60–69 cms. will be taken as representative of the data relating to immature females.

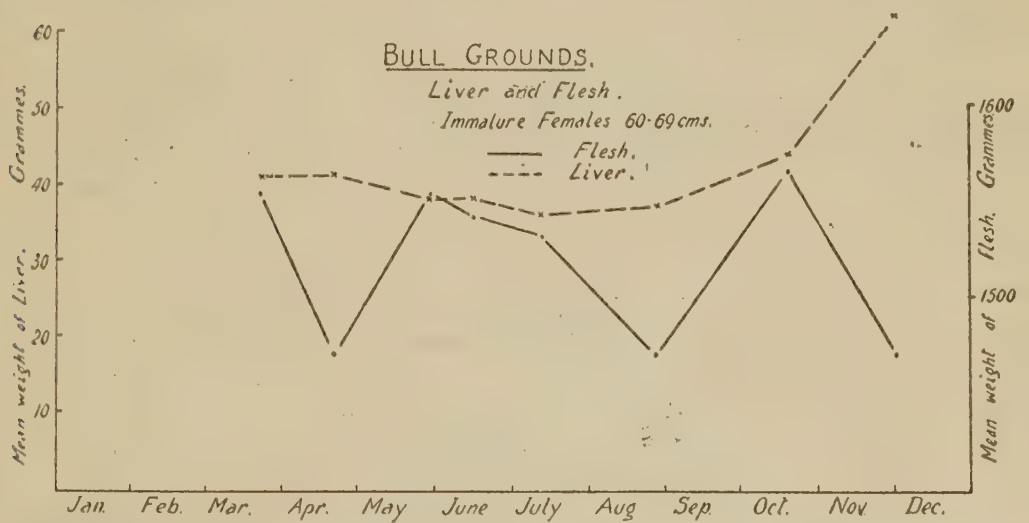

FIGURE 15.—Seasonal changes in mean weight of liver and flesh in immature females, 60–69 cms. Bull grounds. Data in Appendix, Table VIA.

In Figure 15 are drawn two curves representing, respectively, the seasonal variation in the mean weight of the liver and flesh of immature female hake of 60–69 cms., on the Bull grounds. The mean weight of liver has a spring maximum in April, and then falls very slightly until July. Between July and December it recovers to

a value far above that in April. The curve for mean weight of flesh is very irregular, but it would seem that there is a loss in mean weight between June and September. If this is allowed, the liver and flesh in immature females reflect the changes found in adolescent and mature females, though the variations are exceedingly slight.

These observations are, to some extent, confirmed by the length-categories 50–59 cms. and, especially, 70–79 cms.

The autumn recovery of the liver, beyond the spring maximum, presents an interesting problem. As Table VIA shows, this is also found in the smallest length-categories of adolescent females and males, that is, in fish which must be presumed to be growing most rapidly. It may be a result of growth, though, owing to the limitation of the size of the hake in the samples by using the 10 cm. categories, it is hard to see how this could happen. No other explanation offers itself.

In this section, attention will be drawn only to the difference between the spring maximum and the summer minimum in the liver, the autumn maximum being left out of account.

In Table VII are set out the values of k (liver) at the time of the spring maximum and summer minimum. The values of k (liver) both at minimum and maximum increase distinctly with increase in length, but the amplitude of seasonal variation shows no significant change. Owing to the irregularity of the curves for mean weight of flesh, no attempt has been made to work out the values of k (flesh) at minimum and maximum.

Comparing the values of k (liver) with those in adolescent females, it is apparent that the value of k (liver) at minimum is notably higher in adolescent than in immature females. At maximum mean weight, the value of k (liver) in adolescent females is much greater than in immature females, and there is a three-fold increase in the amplitude of the seasonal fluctuation in the mean weight of the liver in adolescent, as compared with immature, female hake.

The increase in the value of k (liver) at the time of minimum mean weight probably means that, in the adolescent female, the permanent tissue in the liver has increased, in order to contain the greater quantity of reserve material required by the adolescent, and still more by the mature fish.

It has been said that one can detect a slight net loss in condition between April or June and July or August. Taking, as before, the 60-69 cms. category as representative of immature females, an attempt may be made to define the order of the apparent seasonal loss of condition in immature female hake.

Between March and August :—

The liver loses 4 gms.

The flesh loses 86 gms.

Total loss relative to length, 90 gms.

This represents a loss of 5·6 per cent. of the weight of these organs at the time of maximum mean weight.

D (5) The seasonal change of condition in Immature, Adolescent, and Mature Female Hake compared.

A fairly well sampled length-category common to immature, adolescent and mature females is the 70-79 cms. category, which will be used to compare the seasonal changes in mean weight of the fish and its organs in the three classes.

In Figure 16 four curves are drawn, representing the seasonal changes in the mean weight of the ovaries of (*a*) mature hake, and (*b*) adolescent hake, of 70-79 and 80-89 cms., respectively, on the Bull grounds. At the time of minimum mean weight, in October, both adolescent and mature roes have approximately the same mean weight. In the spring and early summer, both mature and adolescent roes increase

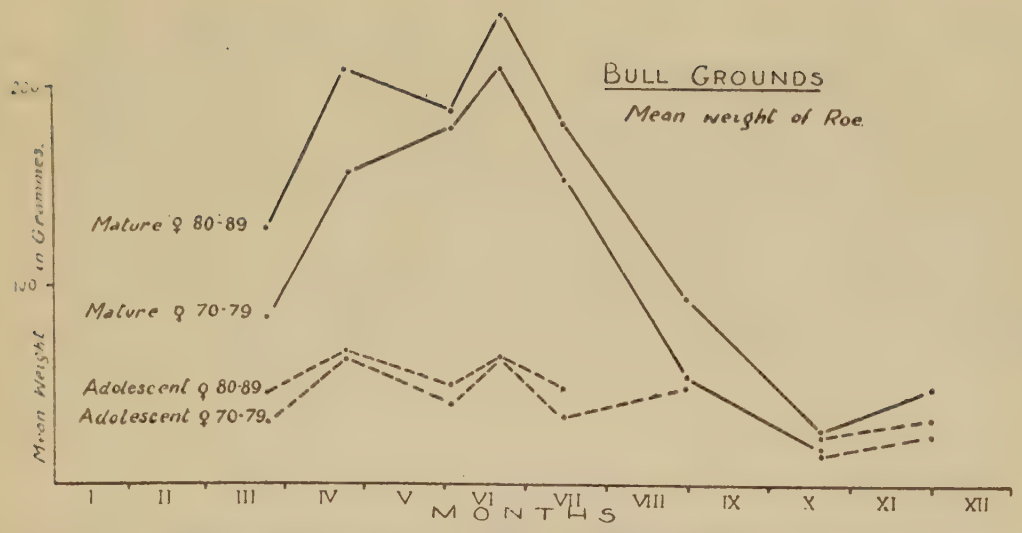

FIGURE 16.—Seasonal changes in mean weight of ovaries of mature and adolescent female hake, 70–79 and 80–89 cms. Bull grounds. Data in Appendix, Table VIA.

in mean weight, the adolescent roes foreshadowing, in a very interesting way, the maturation of the mature roes. But the seasonal maturation of the mature roe is, as Figure 16 shows, vastly greater in extent than that of the adolescent roe ; it has been shown, in Section D (4), that the seasonal fluctuation in mean weight of the mature roe is of the order of three times that of the adolescent roe.

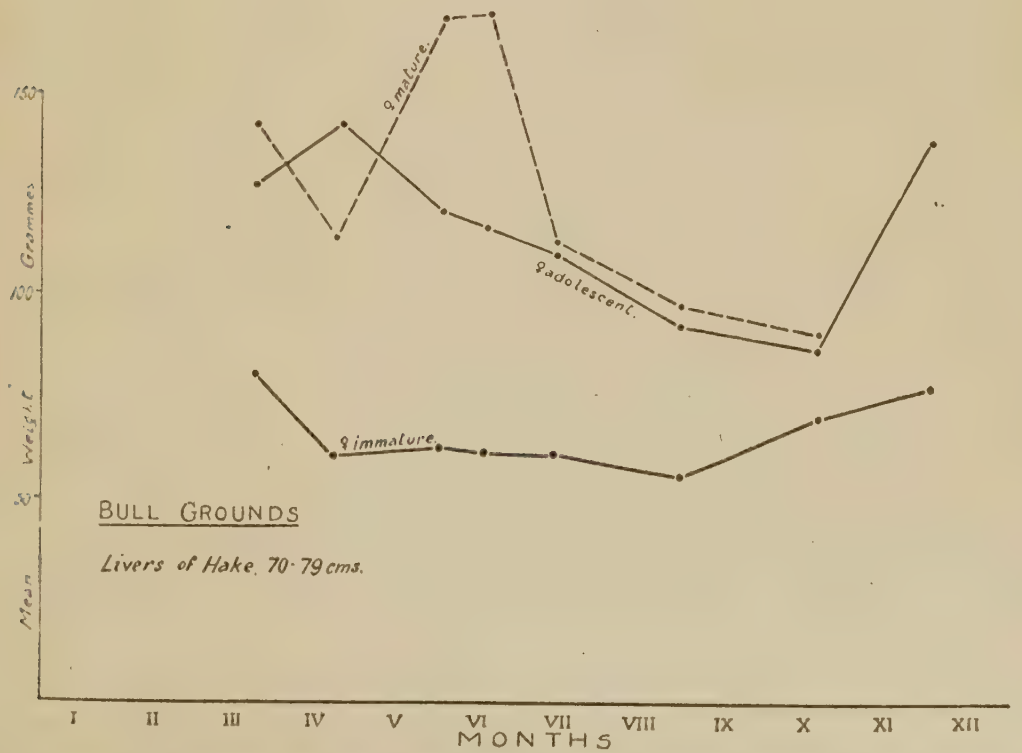

FIGURE 17.—Seasonal changes in mean weight of liver in mature, adolescent, and immature females, 70–79 cms. Bull grounds. Data in Appendix, Table VIA.

In Figures 17 and 18 are drawn curves showing the seasonal variation in liver (Figure 17) and flesh (Figure 18) in (*a*) mature, (*b*) adolescent, and (*c*) immature female hake of 70-79 cms. on the Bull grounds. The nature of the seasonal variation is clearly the same in all three classes of females. All have a relatively high value for liver and flesh in spring, show a loss in weight, relative to length, in the summer and commence to recover in the late autumn and early winter. The very close resemblance between the curves for liver and flesh, respectively, serves to emphasize the fact that the changes taking place in these organs are closely similar in time and nature.

The difference between the mean weights of liver in adolescent and mature females, at the time of minimum mean weight, is very slight, but very considerable as between adolescent and immature females. This has already been mentioned in Section D (4), and is probably due to an increase in the permanent somatic tissues, to enlarge, so to speak, their storage capacity.

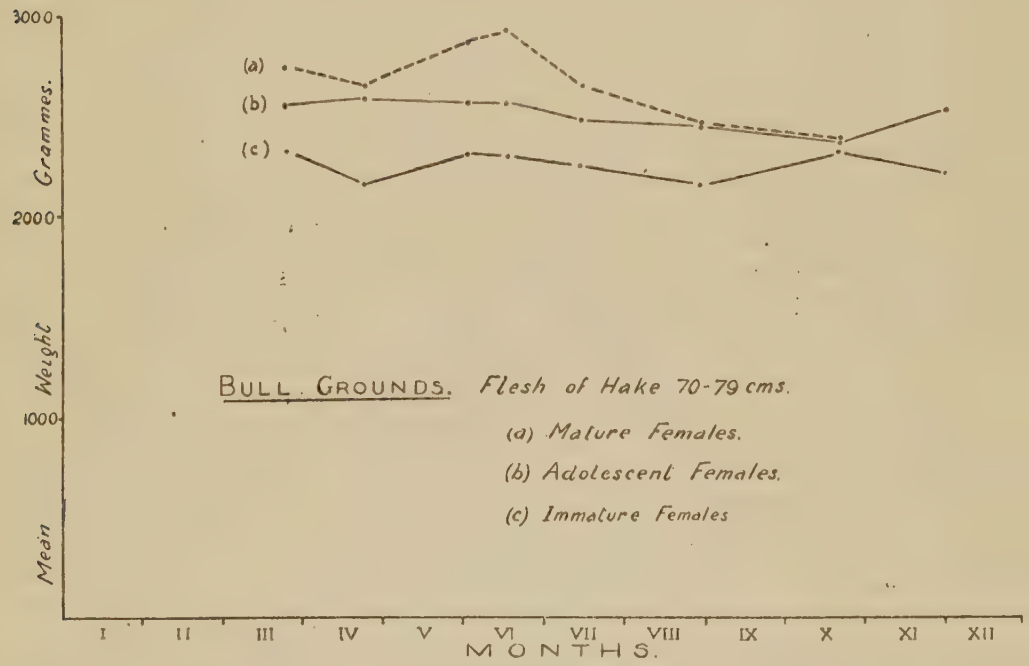

FIGURE 18.—Seasonal changes in mean weight of flesh in mature, adolescent and immature females, 70–79 cms. Bull grounds. Data in Appendix, Table VIA.

At the time of maximum mean weight, on the other hand, there is a great increase in weight from immature to adolescent, and from adolescent to mature females. This great increase in the amplitude of the seasonal variation is clearly associated with the increased activity of the gonads.

We have seen, in Section D (4), that adolescent females lose 10·7 per cent. of their mean weight at maximum, during the seasonal changes in mean weight, and that immature females lose 5·6 per cent. It can easily be shown, by calculation from the data in Table VIA, that mature females lose 21·7 per cent. of their mean weight at maximum, in the course of the seasonal changes in mean weight.

In tabular form :—

Immature females of 60-69 cms. lose 5·6 per cent. of their weight.							
Adolescent	,,	70-79	,,	,,	11·2	,,	,, ,,
Mature	,,	80-89	,,	,,	21·7	,,	,, ,,

If these three length-categories are taken as representative of their respective biological sub-classes, it is clear that the amplitude of their seasonal fluctuation in condition increases, at a rate which is of the order of geometrical progression, from immature, through adolescent, to mature females. It shows that the metabolic strain on the organism doubles itself with the onset of sexual maturity, and that the adolescent phase is intermediate and preparatory between immaturity and maturity.

It will be recollected that, in mature males, the metabolic strain roughly doubles itself in successive 10 cm. length categories (Section D (1)).

To sum up, in all classes of females, and in males (Section D (1)), the fish is in good condition in winter and spring, in poor condition in summer. Some parallel observations on the seasonal change in condition in other fishes may be discussed here. D'Arcy Thompson (1916) has used the data published by the Board of Agriculture and Fisheries, in 1909, to draw a smoothed curve showing the seasonal variations in condition of plaice at a fixed length, 55 cms. He writes, " with unchanging length, the weight, and therefore the bulk, of the fish falls off from about November to March or April, and again, between May or June and November the bulk and weight are gradually restored, The explanation is simple, and depends wholly on the process of spawning, and on the subsequent building up again of the tissues and reproductive organs." Johnstone (1913) however, finds a seasonal variation in *immature* plaice in the Irish Sea. The index of condition rises to a maximum at about the end of July, and is well correlated with the temperature of the sea. He concludes that " immature plaice are in best condition when the sea-temperature is higher, than when it is lower than the mean, a result which was, of course, to be expected." Graham (1923) using the data on Cod published by Russell (1922) shows that there is a heavy loss in condition in March or April, or both, and a recovery culminating in June or July. " This loss of condition is naturally attributed to spawning, and the recovery to the heavy feeding of the spents."

In mature male and female hake, there is obviously a great loss of material due to the shedding of the sexual products, and it is probable that most of the loss in condition during the summer and autumn is due to this. But it is remarkably interesting to find that the seasonal change in condition of immature and adolescent female hake foreshadows so closely this metabolic rhythm in mature fish, and there is a strong suggestion that the spawning cycle, which appears in mature fish, is nothing new, but is the expression of a rhythm already present in the immature fish. The activity shown by the roes of adolescent females is very clearly a foreshadowing of the seasonal rhythm of activity in the mature roes.

Graham (1923) makes this very significant comment on immature Cod, that these reflect the spring loss in condition, which is shown by mature fish as a result of spawning. The data published by Russell (1914), of weighing experiments on cleaned haddock, shows that haddock of 25 cms., which may be regarded as immature, show the same loss of condition, in March, which, in mature fish, is attributed to exhaustion after spawning.

The summer loss in condition of immature and adolescent female hake cannot be adequately explained in terms of nutrition. In the summer, as I have shown in Section K of an earlier paper on the Natural History of the Hake (1927), the hake are feeding chiefly on Clupeoids and Mackerel, which cannot be considered poorer fare than the winter diet of Blue Whiting (*Gadus poutassou*). But the seasonal changes in condition must, in any case, be closely bound up with the growth of the hake, and will be further discussed in that connection, in a future paper.

I do not know of any other Teleostean fish in which there has been suggested a foreshadowing, in non-spawning fish, of the spawning rhythm in mature fish, such as I have suggested occurs normally in the hake. Ford (1919-1922) writes, of the Spur-Dog, " a female, before becoming mature, undergoes an extended period during which her first set of eggs is developing in the ovaries," but the case may not be truly comparable with the hake's pre-spawning maturation. The data referring to

Cod and Haddock, quoted above, point clearly to a reflection, in the somatic tissue of the immature fish, of the spawning rhythm in the mature fish. Cunningham (1895-7), writes, of the Plaice, "aborted partially yolked eggs do occur in immature ovaries . . . it is evident that, in an immature ovary, a small number of eggs are constantly beginning to develop yolk, as though about to become ripe eggs, but almost immediately die and degenerate, instead of continuing their development." The similarity of this phenomenon to that described, for Hake, in Section B, needs no stressing.

I should here re-state my reason for suggesting that there is a pre-spawning maturation in female hake:—a large proportion of the ovaries which, by their naked eye appearance, are clearly not immature, do not, on the advance of the spawning season, ripen in a manner suggesting that they will liberate ripe eggs, but remain small, and only a few of their contained eggs show any activity (Figure 5c). This observation is similar to Cunningham's on the Plaice. It is confirmed by an inspection of the distribution of the weights of active ovaries at different seasons.

In Figure 19 (data in Appendix, Table X) are drawn three percentage frequency curves, showing the distribution of the weights, in 50 gram groups, of the active ovaries* of female hake, between 70 and 89 cms. in length, in early December, March, and June, on the Bull grounds.

In early December, the active ovaries form a single mode in the 1-50 grams group, as might be expected from the knowledge that this is the time of exhaustion in the roes of the hake. In March, at the approach of the spawning season, it is seen that, while a certain proportion of the ovaries have increased greatly in weight, there is still a dominating mode, at 1-50 grams, of undeveloped active ovaries, Finally, in June, at the height of the spawning season, about 40 per cent. of the active ovaries still remain small and undeveloped. These active ovaries, which do not undergo the great increase in weight which leads to spawning, I have termed adolescent ovaries. Hake containing such ovaries are generally of a smaller size than those containing ovaries which ripen normally (Figures 3 and 4).

During the collection of the data at sea, when rapidity rather than great accuracy of diagnosis was required, adolescent ovaries were distinguished from mature ovaries (as mentioned in Section B 2) by their thinner walls, smaller size, and general naked-eye appearance. There has thus been a possibility of confusion and faulty diagnosis between adolescent and mature fish. Yet when the fish are so distinguished by the naked eye appearance of their roes, it is found that there are very significant differences, in the seasonal variation of mean weight of liver and flesh, as between the two classes (Figures 17 and 18), which cannot be explained unless there is a real biological difference between them.

This should not be taken to mean that there is always an adolescent period before full maturity, nor that a fish which has spawned successfully once may not undergo an abortive spawning in subsequent seasons. But it seems certain that, in the majority of cases, there is a pre-spawning maturation, during which significant changes take place in liver and flesh, which are a preparation for the great metabolic strain of spawning.

D (6) Other factors associated with the seasonal change in condition of the Hake.

(*a*) In Figures 1, 2 and 7 are drawn curves representing the seasonal variation in mean weight of the gonad of the typical length-categories of mature females, adolescent females, and mature males respectively. The general trend of these curves can be seen, and has been described in the appropriate places, but there is considerable variation in mean weight from sample to sample, causing the curve to appear very jagged. It will now be shown that these deviations from the general trend are due to differences in the depth from which the samples were obtained.

* "Active ovaries" here refers to both adolescent and mature ovaries, that is, to all ovaries other than immature.

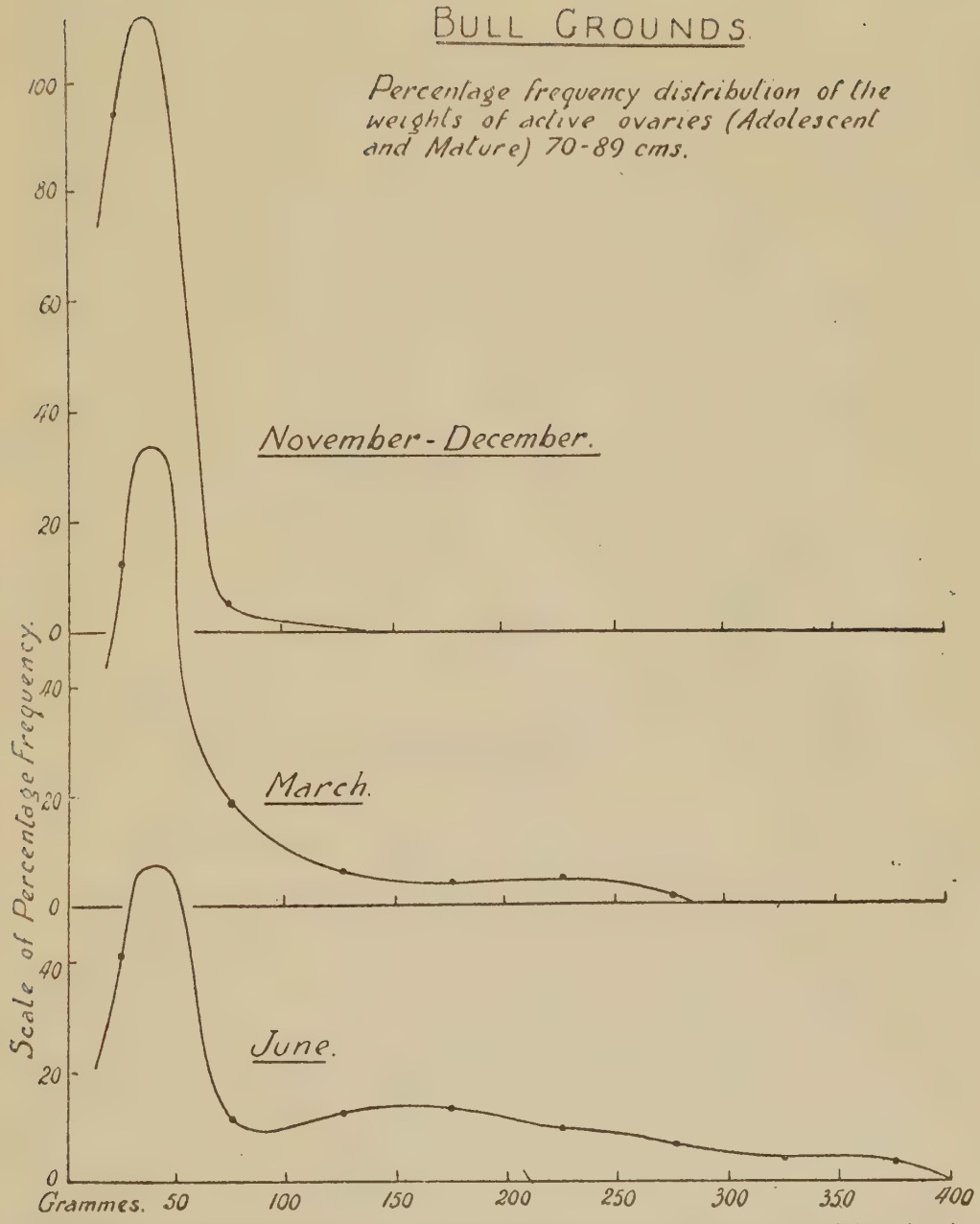

FIGURE 19.—Percentage frequency curves, showing the distribution of the weights of active ovaries in successive 50 gram groups, on the Bull grounds in early December, March and June. Data in the Appendix, Table X.

FIGURE 20.—Seasonal variations in mean weight of the ovary in mature Females of 80-89 cms., with mean depth of capture. All regions. Data in Appendix, Table VIA.

In Figure 20 are drawn two curves. These represent, respectively, the mean weight of the gonad in mature females of 80-89 cms. and the mean depth from which the samples were obtained, in the successive samples throughout the year. The general trend of the two curves is inverse; the depth tends to lessen as the roe grows heavier. The deviations from a smoothed curve through each series can be shown, also, to be inversely correlated. In Figure 20 it may be seen that a high value of roe is associated with a low value of mean depth, and a low value of roe with a high value of mean depth.

The mid-points in a figure similar to Figure 20, but based on all adequate samples in Table VIA and VIB, have been joined and smoothed curves thus obtained. By comparing the deviations from this smoothed curve in mean weight of roe, and mean depth of capture, respectively, the effect of the seasonal variation in each case can be minimised, and the correlation coefficient r can be calculated between mean weight and mean depth.

Figures similar to Figure 20 have been drawn for adolescent females of 70-79 cms. and mature males of 70-79 cms. and the correlation coefficient of the deviations from a smoothed curve for mean weight of gonad, and mean depth of capture,

plotted in these two sub-classes of hake. In the curve for mean weight of testis, ... values from the Norwegian Deep and Skagerrak samples are not included,* ... all cases only fairly well-represented samples have been considered. The data ... to be found in Tables VIA and VIB.

... in mean weight of gonad correlated with deviations in mean depth of capture.

	Values of r and σr in		
	Mature Males (70–79)	Adolescent Females (70–79);	Mature Females (80–89)
r	−·68	−·48	−·75
σr	·112	·19	·088

I consider that these coefficients indicate, in the case of mature males and females ... least, a high degree of correlation between mean depth of capture and mean weight ... gonad, and that the correlation would have been even better if a more accurate ... re to represent the mean depth of a voyage were possible. The anomalies in the ... ves for seasonal changes of mean weight in the gonad (Figures 1, 2 and 7) are to ... explained largely by the differences in the mean depth from which the samples were obtained.

The inverse correlation between depth and mean weight of gonad expresses a ... already fully discussed in Parts I and II of this Natural History (1927), namely, ... the hake makes an invasion of shallow water in order to spawn, although spawn- ... may also take place over deep water (Schmidt, 1910). The correlation should ... be taken to mean that there is a causal connection between the state of develop- ... nt of the gonad, and the depth assumed by the fish; as shown in Parts I and II, ... classes of hake invade the shallow water in spring and summer, the adults spawn- ing as they go, and the observed correlation simply records this fact.

Since the seasonal changes in mean weight of the gonad are accompanied by ... nite changes in the mean weight of the liver and flesh, there should also be a ... tion between mean depth and mean weight of liver and flesh. Speaking generally, ... may be said that the liver and flesh are in good condition when the hake are in ... water in winter and spring; in poor condition when the hake are in shallow ... ter in summer and autumn. A very rapid recovery from exhaustion follows upon the hake's return to deep water.

In the case of *Acanthis vulgaris*, the Spur-dog, I have shown elsewhere (1930), a ... se correspondence between the mean weight of the liver and the mean depth ... capture; the liver is in better condition in deeper than in shallower water, and I ... ve suggested that depth itself involves some factor favouring the storage of reserve ... terial, and especially the storage of unsaponifiable oil. I was inclined to discount ... riations in the quantity of food available at different depths, as a factor concerned in the condition of the liver of the Spur-dog.

Now, Channon (1928) shows, in his Table I, that among Gadoids, as among ... lachians, the percentage of unsaponifiable matter increases as species from deeper ... bitats are examined. The Hake and the Forkbeard (*Phycis blennioides*) alone ... ong the Gadoids examined had a percentage of unsaponifiable matter in the liver ... greater than 1 per cent. Variations in the condition of the liver of the hake, due ... variations in the quantity of unsaponifiable matter, are not to be looked for, and ... same eight stations, at which a relation between liver and depth was found in ... Spur-dog, show no such relation in the hake These stations are set out in Table VIB.

We have seen that the seasonal rhythm in the condition of the liver and flesh ... the hake, a rhythm associated with a spawning period from March or April to ... August, requires a rapid and effective storage of reserve material in the winter and ... spring. This rhythm is already present in immature fish. It seems to me that, ... though the withdrawal of all classes of hake to the deep water in winter may, in part

* They are dealt with in Section D (7), page 51, and Figure 22.

be directly associated with the fall in mean temperature in the shallow water, as shown in Section O of Parts I and II, it is mainly associated with nutrition. I have shown, in Section K of that report, that, in the summer in shallow water, the hake feeds chiefly on clupeoids and mackerel; in winter, in deep water, chiefly on the Blue Whiting (*Gadus poutassou*). Now, the herring and mackerel shoals in the Irish area break up and disappear in the autumn, while, at this time, the shoals of blue whiting are concentrating for their spawning over the deep water. I have suggested, in Parts I and II, that the midwinter recovery in the catches of hake is due to the concentrations of hake on the edge of the deep water to feed on the blue whiting, and I have shown elsewhere (1928) that, in the spring of 1927, there was a correlation between the abundance of blue whiting and the catches of hake to the west and north-west of Scotland. The urgent need of the fish to place itself in the best conditions for the re-stocking of its liver and flesh with reserve material may be the chief factor in the withdrawal of the hake to the deep water in the winter, and in the rapid recovery which takes place there.

(*b*) I was very early aware of a *regional* variation in the weight of liver and flesh of the hake (*i.e.*, of the fish, less gonad and gut). In three successive voyages, in January, February and March, 1926, I visited the St. Kilda, Westward and Bull grounds, and was struck by differences between the mean weights of the liver and flesh of the hake, on these three grounds, which could not be explained in terms of a varying degree of development of the gonad. For this reason, in Sections D (1) to D (6) the seasonal rhythm in the mean weight of the hake and its organs has been followed on one fishing ground, the ground "Below the Bull." The regional variation in the mean weight of liver and flesh, relative to length, will now be dealt with.

Firstly, however, it may be said that, since the anomalies in the curves for mean weight of gonad (Figures 1, 2 and 7) are due to differences in the depths of the sampling, no regional variation in the mean weight of gonad is to be expected.

Consistently with the practice throughout the paper, the 80–89 cms. category will be taken as representative of mature females, the 70–79 cms. category as representative of mature males and adolescent females, and the 60–69 cms. category as representative of immature females. A comparison of the regional variations will be confined to the deep water hake grounds Westward, Bull, Tory Island, St. Kilda and Butt of Lewis (*see* chart in Frontispiece).

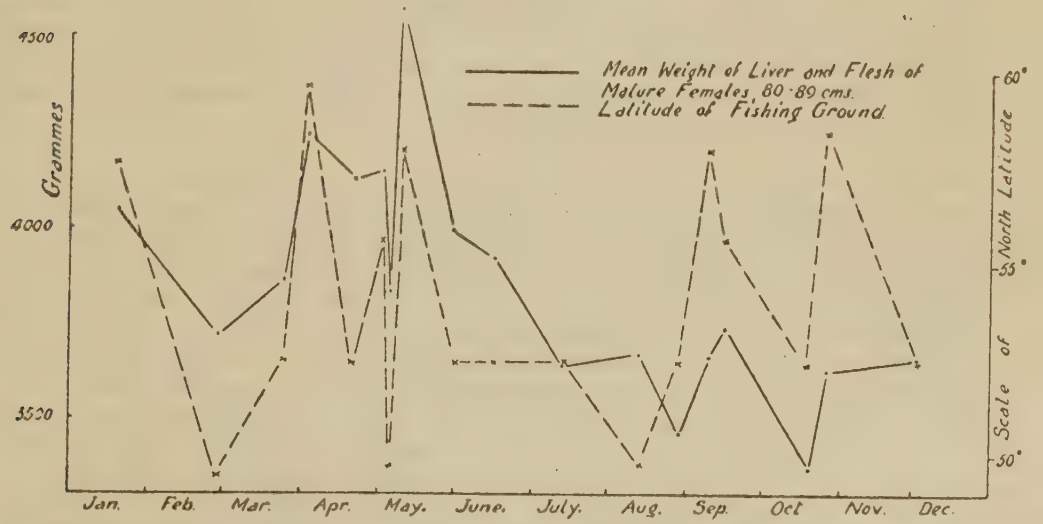

FIGURE 21.—Seasonal variation in mean weight of liver and flesh, combined, in mature females of 80–89 cms. (scale to left), with variation in the latitude from which the samples were obtained (scale to right). Data in the Appendix, Table VIA.

In Figure 21 two curves are drawn. These represent, respectively (1) the variation from sample to sample, arranged in seasonal order, of the combined mean weights of liver and flesh in mature female hake of 80–89 cms. on the fishing grounds named, and (2) the latitude of the fishing grounds which provided the samples. The two curves are seen to agree closely, showing that the anomalies from a curve representing the seasonal change in condition of the liver and flesh are associated with variations in latitude. The data are taken from Tables VIA and VIB.

Figures similar to Figure 21 may be drawn, based on the data relating to mature males, adolescent females, and immature females, and it may be seen that, in all classes of hake, the association between latitude and mean weight of liver and flesh, holds good.

The correlation coefficients r may be calculated by correlating the deviations from smoothed curves obtained by joining the mid points in Figure 21 (for mature females), and in similar figures drawn for the remaining classes of hake.

Deviations in mean weight of liver and flesh correlated with deviations from a smoothed curve for latitude.

	Values of r and σr in			
	Immature females (60–69 cms.)	Adolescent females (70–79 cms.)	Mature females (80–89 cms.)	Mature males (70–79 cms.)
r	·85	·79	·85	·81
σr	·07	·10	·07	·09

It is seen that, in all classes of hake, there is a high positive correlation between the mean weight of the liver and flesh (relative to length) and the latitude. On the deep water Atlantic hake grounds, the weight of liver and flesh (*i.e.*, of the fish less gonad and gut) increases, relative to length, from south to north.

I am at a loss to explain why hake should be heavier at a given length on northerly than on southerly hake grounds. One can suggest three possibilities; (*a*) since there is probably no regional variation in the quantity of eggs and sperm produced, a greater amount of reserve material may be required to produce a given quantity of eggs and sperm in more northerly (and slightly colder) waters; (*b*) food becomes more suitable or more abundant in northerly waters; or (*c*) there is a difference in the manner of growth, hake from more northerly waters growing more rapidly in weight, with reference to length, than in more southerly waters.

The second suggestion is not very probably true, since the chief food of the hake on the deep-water grounds is the blue whiting (Hickling 1927 and 1928), and Schmidt (1910) classifies this species as a southern, warm-weather, Atlantic species, which one would expect to become rarer, rather than more abundant, from south to north.

I incline to the third suggestion, that in more northerly waters the hake grows more slowly in length, but more rapidly in weight, than in more southerly waters; in other words, the fish has a slightly different shape, becoming relatively less slender as the more northerly shoals are sampled. As far as growth in length is concerned, the suggestion certainly derives support from the work of Belloc (1929) who finds that, from Morocco north to Ireland, excluding a dwarf race of hake in the Mediterranean, the rate of growth in length diminishes with increase of latitude. His data, based on scale readings, are necessarily somewhat scanty, and I hope, in a future paper, to work out the growth rate of the hake on fishing grounds widely separated in latitude, and so test my hypothesis.

I know of no other fish in which a variation in weight, with latitude, has been suggested. Johnstone (1910) found consistent variations in the condition of immature plaice from Barrow Channel, Rock Channel, and Beaumaris Bay, but he concludes that "one can hardly regard these differences as indicative of different varieties or races of plaice, in the way one would so interpret structural differences."

D (7). The Hake in the Norwegian Deep, Skagerrak and Firth of Clyde.

A study of the distribution of hake in the North Sea, throughout the seasons, led to the suggestion, in Parts I and II (1927) that "there is a sharp discontinuity in the distribution of hake in the most northerly regions of the fishery. There is, on the one hand, the main Atlantic stock, and there is also the isolated stock of hake which winters in the Norwegian Deep Water. It seems very likely that these hake may form a permanent North Sea stock." This was confirmed by the exploratory voyages of the *Florence Brierley* in the spring of 1927, when we found that "there was no continuous distribution of hake between the Norwegian stock and the main Atlantic Slope stock" (Hickling, 1928).

In June, 1928, a voyage was made to the Norwegian Deep and Skagerrak, during which a good sample of hake, obtained from a considerable number of hauls in each region, was weighed and examined. The data are set out in Table VIA.

We have seen, in Section D (6), that on the Atlantic deep-water hake grounds, the weight of the fish increases, relative to length, from south to north. We shall now compare the Skagerrak sample (as representative of the Norwegian hake stock) with the sample of hake from the most northerly Atlantic hake ground, namely, the Butt of Lewis. To minimise the effect of the seasonal variation in mean weight of liver and flesh, both samples will be compared with the nearest Bull sample, thus the Butt of Lewis sample will be compared with the April sample from the Bull grounds, the Skagerrak sample with the June sample from the Bull grounds.

In Table XI there are four columns. In the first column are set out the mean values of k liver, and k flesh, in all available length-categories of the sub-classes of hake, in the April sample from the Bull grounds. In the second column are set out the corresponding values in the Butt of Lewis sample, with the percentage of the corresponding Bull value. In the third and fourth column a similar comparison is made between the June sample from the Bull grounds and the Skagerrak sample.

From Table XI it is seen that :—

(1) The Butt of Lewis values of k (liver) vary from 88 per cent. to 220 per cent. of the Bull values, with a mean value 154 per cent. of the Bull values.

(2) The Skagerrak values of k (liver) vary from 133 per cent. to 246 per cent. of the Bull values, with a mean value 180 per cent. of the Bull values.

(3) The Butt of Lewis values of k (flesh) vary from 94 per cent. to 118 per cent. of the Bull values, with a mean value 104 per cent. of the Bull values

(4) The Skagerrak values of k (flesh) vary from 106 per cent. to 122 per cent. of the Bull values, with a mean value 113 per cent. of the Bull values.

From what has been said in D (6), it is understandable that the Butt of Lewis hake, taken from the most northerly Atlantic hake ground, should have values for k (liver) and k (flesh) respectively 54 per cent. and 4 per cent. greater than the Bull values. But the Skagerrak values are of the order of twice and three times this variation, respectively, and show that the Norwegian hake have a relation between weight and length different from that of any of the Atlantic hake, and much greater than any variation, due to latitude, on the Atlantic hake grounds.

This may be confirmed by plotting, from the data in Table VIA, length-weight curves for liver and flesh. It is found that there are only slight variations in the position of the curves for all the Atlantic hake grounds, the variations being due to latitude and season, but the curves for the Norwegian Deep and Skagerrak samples stand sharply distinct from any of these, owing to the much greater weight of liver and flesh, relative to length, in the Norwegian hake.

It was suggested, in Section D (6), that the increase in the mean weight of the hake, relative to length, with increase of latitude, is due to a slight change of shape, the fish becoming progressively less slender from south to north. But Table XI shows that the increase in the value of the coefficient k (flesh) is only of the order of 4 per cent. on the Atlantic hake grounds, and, as far as I know, the difference in shape (if the regional variation is indeed due to this) is too slight to be noticeable to the eye. But a glance at a haul of Norwegian hake gives one the impression that these are thicker in the body than those met with on the Atlantic Slope. Some of the specimens looked absurdly squat, and one had almost the profile of a carp or herring.

Some of the weights of these "stumpy-tailed" hake, with the approximate mean weight of all Norwegian hake of the same length, and the approximate mean weight of Bull hake of the same length, in June, are given below, to illustrate this shortness and thickness in the body.

Length.	Weight of flesh of "Stumpies."	Average weight of all Norwegian hake of the same length.	Average weight of Bull hake of the same length.
♀ 75	3,300	2,940	2,700
♀ 75	3,800		
♀ 71	3,000	2,500	2,300
♀ 69	2,400	2,200	1,980
♀ 66	1,900	1,900	1,730
♂ 63	1,600	1,580	1,410
♂ 62	1,800	1,590	1,320

The table shows that the "stumpy-tailed" hake were much heavier than the average Norwegian hake of their length, just as the average Norwegian hake was much heavier than the average Bull hake, length for length. In my view, the "stumpy-tailed" hake are only extreme examples of the shorter and thicker body in the Norwegian, as compared with the Atlantic, hake.*

A second point in which the Norwegian hake differ from the Atlantic hake is in the mean weight of the testis. In Figure 22 are drawn curves representing the increase in weight of the testis, with increase in the length of the fish, in the Skagerrak sample, and in the April sample from the Bull grounds, when the testis had its maximum mean weight there.

The testis, in the Skagerrak sample, shows a weight, and a rate of increase in weight with increase of length, vastly greater than in the Bull sample. In this respect the Norwegian hake differ very sharply from any of the Atlantic hake. It is because of this exceptional nature of the Norwegian hake that I have omitted the values for the Norwegian Deep and Skagerrak in calculating the correlation between depth and mean weight of gonad in Section D (6).

Thirdly, in the females, adolescence and maturity set in at a much smaller length in the Norwegian hake than in any of the Atlantic hake. This may be seen by an inspection of Figure 4.

The peculiar length-weight relationship in the Norwegian hake, the exceptionally high mean weight of the testis in the males, and the exceptionally early onset of maturity in the females, all find an explanation if it is granted (*a*) that the Norwegian hake grow more slowly in length, though not in weight, than the Atlantic hake, and (*b*) that, in hake, the time of onset of sexual maturity is a matter of age. For if these are granted, Norwegian hake are older at any given length than Atlantic hake,

* Stumpy-tailed hake are, however, not uncommon on other grounds.

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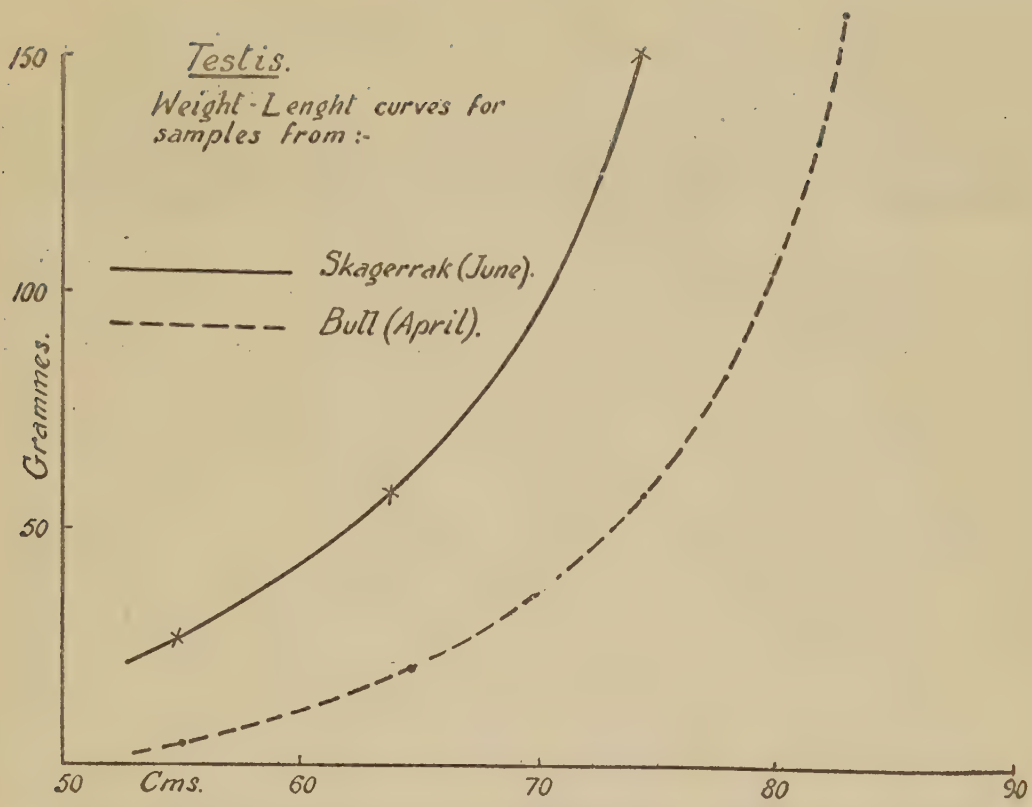

FIGURE 22.—Curves showing the length-weight relation of the testis in the Skagerrak hake, and in the April sample from the Bull grounds. Data in the Appendix, Table VIA.

and sexual maturity will set in at a smaller length. In females, this will account for their early maturity, and in males, since (*a*) the males at any length will be older than the males in the Atlantic shoals, and (*b*) the mean weight of the testis cubes itself with successive increments of length, and therefore increases rapidly with increase of age, both the mean weight of testis and the rate of increase will be much greater in the Norwegian than in the Atlantic hake.

To sum up :—in their relation of weight to length, in the very high mean weight of the testis, and in the early maturity of the females, the Norwegian Deep and Skagerrak hake resemble each other very closely, but differ sharply from any of the Atlantic hake, and one can definitely suggest that these hake form an isolated stock, living in conditions which cause them to grow in a peculiar manner, distinct from the Atlantic hake.

The sample of hake obtained from the Clyde in July, 1929, offers very great difficulties when an attempt is made to compare it with the samples from deep-water hake grounds. Whereas even the Norwegian Deep and Skagerrak samples were taken from depths comparable with those from which the Atlantic Slope samples were obtained, the Clyde sample was taken at a mean depth of 30 fathoms. Secondly, the shoals consisted almost wholly of mature and actually spawning males and females, the females in particular being in a much more advanced condition than any of those in the deep-water samples (*see* data in Table VIA). Immature and adolescent females were almost absent, as one would expect in an actively spawning shoal.

The mean weights of gonad, liver and flesh show no marked difference when compared with the Atlantic hake. Sexual maturity seems to set in exceptionally early; thus, one mature female was found in the 50–59 cms. category and 39 in the

60-69 cms. category. But the shallowness of the water fished would result in a selection of the smaller mature females, for it is a fact that, generally speaking, the smaller hake of any class are found in shallower water, the larger in deeper water. The data referring to Donegal Bay in September (42 fathoms) and to Bantry Bay (29 fathoms) and Galway Bay (55 fathoms), in Tables VIA and VIB, show the same phenomenon to a smaller degree. On the whole, the data referring to weight and maturity offer no evidence as to whether the Clyde hake form an isolated stock, distinct from the Atlantic hake, such as we have shown the Norwegian hake to be.

SUMMARY.

This paper deals with the seasonal changes undergone by the gonads of the hake, and with the associated changes in the liver and flesh (by which is here meant the gutted fish). The work is based entirely on fluctuations in mean weight, and no chemical analyses have been attempted. The method of investigation has been, to make a series of voyages on commercial trawlers, and to obtain data as to length, sex, condition and weight of gonad, liver and flesh. The data have been grouped according to sex and maturity, and, within each group, into 10 cms. categories. The seasonal variations in mean weight in each 10 cm. category of each sub-class of hake have been used to trace the seasonal change in condition.

The weight-determinations were all made at sea, in all conditions of weather, but proof is given that a reasonably accurate determination is possible, especially when the mean of a number of weighings is taken (Section A).

Male hake become mature very early; in a series of counts made in August, 50 per cent. of the males were mature at 27 cms. whereas, in female hake, maturity sets in much later, usually between 60 and 70 cms. There are, however, regional variations in the length at which maturity sets in among female hake (Section B).

It was found necessary to distinguish females into three classes, namely, immature, adolescent and mature. The adolescent class was established because it was found that a large proportion of ovaries, which, by their appearance and structure, were clearly not immature, did not, on the advance of the spawning season, ripen in a manner suggesting that they would liberate ripe eggs, but remained small, and only a few of their contained eggs showed any activity (Sections B and D (5)). Adolescent and mature ovaries were further sub-divided into maturity stages. These are described and illustrated with photographs of sections (Section B (2)).

The seasonal changes in the proportion of each arbitrary maturity stage are discussed; among mature females, spent ovaries are most abundant from October to January, while ovaries in the penultimate stage of ripeness increase in proportion, from January to June, and decline to nil in October and early December. These results are confirmed by the seasonal fluctuation in mean weight of mature ovaries, and by the commercial landings of hake roes. This orderly increase and decrease in the percentage of roes in the penultimate stage of ripeness points to a spawning season at its height in July, though female hake in the ultimate, or running, condition were only rarely and irregularly met with, from March to September

Among adolescent females, ovaries in the most advanced yolky condition are most abundant in the summer months, and it is clear that adolescent females foreshadow very closely the seasonal rhythm in fully mature females (Section B (3)).

In Section C is discussed the question of the regeneration of eggs in the spent ovary, and the conclusion is reached that, in the ovary of the hake, there is no need to look for a new formation of oocytes, whether by mitosis or by a metamorphosis of follicle cells. The absence of oogonia and young oocytes in the ripe ovary is apparent only—there are actually enough of these amply to cover the whole output of eggs by the female hake during its lifetime.

The seasonal variations in the mean weight of the mature testis and mature ovary are, in the main, very similar. Both have their minimum mean weight in about October, show some recovery by early December, and then increase in weight to a maximum in the summer. Both remain at a high mean weight from April to July, which must consequently be regarded as the time of most effective spawning. The spawning season seems to be longer in the male than in the female (Section D (3)).

The seasonal changes taking place in the liver and in the flesh are very closely related to each other. In males, and in all classes of females, the liver and flesh are

heaviest, relative to length, in winter and spring, and in poor condition in summer and autumn. By comparison with the changes taking place in the gonad, in mature males and females the greater amount of the material lost from the liver and flesh probably goes to nourish the gonads. But it is interesting and important to find that this rhythm in the somatic tissues is already foreshadowed in adolescent and immature females, which do not spawn (Section D (5)).

These seasonal changes in the gonads and somatic tissues can also be demonstrated in the commercial landings of hake livers and roes (Section D (3)).

In mature males the amplitude of the seasonal variation in mean weight of testis, and of the somatic tissues, increases with increase of length at a rate which is of the order of geometrical progression (Section D (1)). Within each sub-class of females, however, there is no regular increase in the amplitude of the seasonal variation in the gonads and somatic tissues, with increase of length. In length-categories taken as typical of each sub-class of females, there is an increase in the amplitude of the seasonal variation in mean weight, from immature, through adolescent, to mature females, which is of the order of geometrical progression (Section D (5)).

In adolescent females, the ovary, while foreshadowing closely the seasonal changes in the mature ovary, never exceeds, at its maximum mean weight, one-third of the mean weight of the mature ovary at its maximum. Adolescent females show a very distinct increase in the mean weight of their liver and flesh, length for length, as compared with immature females, not only at the time of maximum mean weight, but also at the time of minimum mean weight. It is suggested that this is due to an increase in the bulk of the permanent tissues of the adolescent female, to cope with the increased strain of maturity. Mature females show only a slight increase in mean weight of liver and flesh, at minimum, over adolescent females (Section D (5)).

While these seasonal changes are taking place in the gonads and somatic tissues, the hake migrates from deep to shallow water, and back to deep water, in such a way that a high inverse correlation can be shown between the mean weight of the gonad in mature fish, and the mean depth of capture. The hake advances into shallow water as the gonads ripen, and returns to deep water when they become exhausted (Section D (6)).

There seem to be no regional differences in the output of the gonads, but there is a regional variation in the condition of the somatic tissues, such that, on the Atlantic deep-water hake grounds, a high correlation can be shown between mean weight and latitude, the hake, of all classes, becoming heavier from south to north. It is suggested that this is due to a difference in the manner of growth, the fish being slightly thicker in the body on more northerly grounds (Section D (6)).

The hake present in the Norwegian Deep and Skagerrak resemble each other very closely but differ from any of the Atlantic hake, in their relation of weight to length, in the very high mean weight of testis in the males, and the very early onset of maturity in the females ; they appear to form a distinct hake stock. The hake examined in the Firth of Clyde, however, were unsuitable for a comparison with those taken in the deep water fisheries, and their condition cannot be used as a means of testing whether they form an isolated stock distinct from the Atlantic hake (Section D (7)).

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APPENDIX.

TABLE I.

Experiments at sea with Arbitrary Lead Weights.

Percentage error.	Series (i) Faroe-Shetland Channel. March, 1927.	Series (ii) Butt of Lewis April, 1927.	Series (iii) Rockall Bank April, 1927.	Mr. Syd. Leech. April, 1927.
−15 per cent. to −10 per cent.		1	2	
−10 per cent. to − 5 per cent.	7	2	2	1
− 5 per cent. to − 0 per cent.	7	6	4	2
0 per cent. ...	4	10	5	5
0 per cent. to + 5 per cent.	7	8	7	4
+ 5 per cent. to + 10 per cent.	3	3	7	6
+ 10 per cent. to + 15 per cent.			2	2
Total	28	30	29	20
Resultant mean error ...	−1·0 percent.	+0·4 per cent.	+1·6 per cent.	+3·4 per cent.

TABLE II.

Maturity of Male Hake, August, 1928.

Galley Head, Galway Bay, and Bull Stations Combined.

Length.	Immature.		Mature.	
Cms.	Frequency.	Percentage.	Frequency.	Percentage.
15	5	100		
16	27	100		
17	42	100		
18	59	100		
19	50	100		
20	36	97	1	3
21	28	100		
22	35	100		
23	35	97	1	3
24	26	96	1	4
25	27	84	5	16
26	20	67	10	33
27	15	48	16	52
28	20	54	17	46
29	8	27	22	73
30	9	23	30	77
31	8	18	37	82
32	4	10	37	90
33	5	10	47	90
34	2	4	55	96
35	2	4	47	96
36	2	3	63	97
37			36	100
38			37	100
39	2	7	28	93
40			28	100
41			19	100
42			20	100
43	1	4	23	96
44			16	100
45			14	100
46			11	100
47			18	100
48			21	100
49			8	100
Totals ...	468		668	

TABLE III.

Measurements of the Diameters of Eggs from Sections of Fixed Ovaries

Micrometer Divisions.	Newly Spent. Donegal Bay, Sept., 1927. 66 cms.	Spent. St. Kilda, Jan., 1926. 88 cms.	Recovering. St. Kilda. Jan., 1926. 78 cms.
	Frequency of Diameters.	Frequency of Diameters.	Frequency of Diameters.
1—5	17 } 42	11 } 37	— } 8
6—10	25 }	26 }	8 }
11—15	39 } 59	16 } 34	14 } 34
16—20	20 }	18 }	20 }
21—25	8 } 14	18 } 31	13 } 28
26—30	6 }	13 }	15 }
31—35	2 } 3	3 } 5	4 } 7
36—40	1 }	2 }	3 }
41—45		3 } 5	7 } 12
46—50		2 }	5 }
51—55			8 } 11
56—60			3 }
61—65			1 } 8
66—70			7 }
Totals	118	112	108

Micrometer Divisions. 29 divisions=100μ.

Table IV.

Arbitrary Classification of the Roes of Hake.

Frequency of each maturity stage throughout the seasons.

Frequency in upright, percentage frequency in italic numerals.

Voyage.	Month and Year.	Adolescent.			Mature			
		Commencing.	Intermediate.	Advanced.	Spent.	Recovering.	Ripe.	Running.
Sir Mark Sykes.	January, 1926	46	43	10	77	33	8	
		46·5	*43·4*	*10·1*	*65·2*	*28·0*	*6·8*	
Tamura III	February, 1926	46	20	29	37	60	36	
		48·4	*21·1*	*30·5*	*27·8*	*45·1*	*27·1*	
Tamura IV	March, 1926	20	39	35	26	44	80	4
		21·3	*41·5*	*37·2*	*16·9*	*28·6*	*51·9*	*2·6*
Florence Brierley I	March-April, 1927	59	21	37	25	80	35	
		50·4	*18·0*	*31·6*	*17·9*	*57·1*	*25·0*	
Tamura V	April, 1926 ...	15	24	46	10	35	68	7
		17·7	*28·2*	*54·1*	*8·3*	*29·2*	*56·7*	*5·8*
Florence Brierley II (Tory I.)	April-May, 1927	10	13	25	2	16	40	
		20·8	*27·1*	*52·1*	*3·4*	*27·6*	*69·0*	
Notre-Dame des Dunes	April-May, 1928	17	16	22	2	31	121	10
		30·9	*29·1*	*40·0*	*1·2*	*18·9*	*73·8*	*6·1*
Florence Brierley II St. Kilda)	April-May, 1927	46	17	19	10	30	59	
		56·1	*20·7*	*23·2*	*10·1*	*30·3*	*59·6*	
Tamura VI	May-June, 1926	48	44	62	7	10	142	1
		31·2	*28·6*	*40·2*	*4·4*	*6·3*	*88·7*	*0·6*
Tamura VII	June, 1926 ...	69	32	97	2	10	129	2
		34·8	*16·2*	*49·0*	*1·4*	*7·0*	*90·2*	*1·4*
Iolite ... Norwegian Deep)	June, 1928 ...	92	100	79	4	1	98	
		33·9	*36·9*	*29·2*	*3·9*	*1·0*	*95·1*	
Iolite ... Skagerrak)	June, 1928 ...	14	69	118			95	
		7·0	*34·3*	*58·7*			*100·0*	
Tamura VIII	July 1926 ...	66	31	38	25	3	90	
		48·9	*23·0*	*28·1*	*21·2*	*2·5*	*76·3*	
Västerhavet	July, 1929 ...			8	3	18	156	66
				100·0	*1·2*	*7·4*	*64·2*	*27·2*
George Bligh	August, 1928	3	2	5	53	19	26	
		30·0	*20·0*	*50·0*	*54·1*	*19·4*	*26·5*	
Florence Brierley III	September, 1927	27	7	23	35	22	12	4
		47·4	*12·3*	*40·3*	*47·9*	*30·1*	*16·4*	*5·5*
Tamura IX	October, 1926	25	5		14			
		83·3	*16·7*		*100·0*			
Kumu ...	October, 1928	19	9	3	107	41		
		61·3	*29·0*	*9.7*	*72·3*	*27·7*		
Tamura II	November-December, 1925	35	22		12	8		
		61·4	*38·6*		*60·0*	*40·0*		

Table V.

Onset of sexual maturity with length in Female Hake. Data divided into Regions.

Column 1. Immature females.
2. Adolescent females.
3. Mature females.

The upright figures are frequencies, The italic figures are percentage frequencies.

(*a*) Bull Grounds.

Length cms.	March, 1926.			April, 1926.			May-June,			June, 1926.			July, 1926.		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
50–54	37			39			39			33			51		
	100			*100*			*100*			*100*			*100*		
55–59	53			46			59			54			61		
	100			*100*			*100*			*100*			*100*		
60–64	41	1		51	2		76	1		73	1		60	1	
	98	*2*		*96*	*4*		*99*	*1*		*99*	*1*		*98*	*2*	
65–69	54	9	1	30	9	1	84	12		91	22		71	8	
	84	*14*	*2*	*75*	*23*	*2*	*88*	*12*		*81*	*19*		*90*	*10*	
70–74	21	23	8	15	28	6	56	50	5	42	56	2	48	46	8
	41	*44*	*15*	*31*	*57*	*12*	*50*	*45*	*5*	*42*	*56*	*2*	*47*	*45*	*8*
75–79	11	41	27	2	26	16	24	64	38	27	86	24	24	57	25
	14	*52*	*34*	*5*	*59*	*36*	*19*	*51*	*30*	*20*	*63*	*17*	*23*	*54*	*23*
80–84	2	15	39		14	22	4	20	45	2	26	55	3	20	36
	3	*27*	*70*		*39*	*61*	*6*	*29*	*65*	*3*	*31*	*66*	*5*	*34*	*61*
85–89		5	35		4	19	1	4	30	1	2	35	1	4	19
		12	*88*		*17*	*83*	*3*	*11*	*86*	*3*	*5*	*92*	*4*	*17*	*79*
90–94			20			21			18			16			19
			100			*100*			*100*			*100*			*100*

(*a*) Bull Grounds—*continued.* (*b*) Tory Island.

Length cms.	August, 1928.			October, 1926.			November-December, 1925.			April, 1927.			September, 1927.		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
50–54	31			38			29			1			13		
	100			*100*			*100*			*100*			*100*		
55–59	24			73			54	4		9			26		
	100			*100*			*93*	*7*		*100*			*100*		
60–64	24		1	88	1		47	4		15			20		
	96		*4*	*99*	*1*		*92*	*8*		*100*			*100*		
65–69	13	5	3	80	2		33	8		4	2		25	1	1
	62	*24*	*14*	*98*	*2*		*80*	*20*		*67*	*33*		*92*	*4*	*4*
70–74	8	2	31	38	13	1	17	10		8	9	3	12	4	
	19	*5*	*76*	*73*	*25*	*2*	*63*	*37*		*40*	*45*	*15*	*75*	*25*	
75–79	1	3	30	16	9	1	10	20		1	23	2	1	13	5
	3	*9*	*88*	*61*	*35*	*4*	*33*	*67*		*4*	*88*	*8*	*5*	*69*	*26*
80–84			17	2	5	5	4	9	5	2	13	14	1	1	5
			100	*16*	*42*	*42*	*22*	*50*	*28*	*7*	*45*	*48*	*14*	*14*	*72*
85–89				2	1	4			4		1	11			8
				29	*14*	*57*			*100*		*8*	*92*			*100*
90–94						2									
						100		1	4			17			8
								20	*80*			*100*			*100*

TABLE V—*continued.*

(*c*) WESTWARD GROUND. (*d*) ST. KILDA.

Length cms.	February, 1926.			April-May, 1928.			August, 1928			January, 1926.			May, 1927.		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
50–54	30	1		40			14			43					
	97	*3*		*100*			*100*			*100*					
55–59	27	6		38	3		12			44					
	82	*18*		*93*	*7*		*100*			*100*					
60–64	38	20		19	9		12	1		33	4		3		
	66	*34*		*68*	*32*		*92*	*8*		*89*	*11*		*100*		
65–69	29	19	2	9	8		5	3		26	8		19	2	
	58	*38*	*4*	*53*	*47*		*63*	*37*		*76*	*24*		*90*	*10*	
70–74	27	22	7	1	13	7	2	1	6	18	27	6	14	25	
	48	*39*	*13*	*5*	*62*	*33*	*22*	*11*	*67*	*35*	*53*	*12*	*36*	*64*	
75–79	5	14	11		20	38			5	9	36	14	1	38	3
	16	*47*	*37*		*34*	*66*			*100*	*15*	*61*	*24*	*2*	*91*	*7*
80–84	1	10	27		5	45			13	2	19	22	2	14	10
	3	*26*	*71*		*10*	*90*			*100*	*5*	*44*	*51*	*8*	*54*	*38*
85–89			25			40			9		3	33		3	32
			100			*100*			*100*		*8*	*92*		*9*	*91*
90–94						20			4			15		1	35
						100			*100*			*100*		*3*	*97*

(*d*) ST. KILDA—*continued.* (*e*) BUTT OF LEWIS. (*f*) NORWEGIAN DEEP. (*g*) SKAGERRAK.

Length cms.	September, 1927.			October, 1928.			March, 1927.			June, 1928.			June, 1928.		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
50–54	5			19			4			47	65		9	28	
	100			*100*			*100*			*42*	*58*		*24*	*76*	
55–59	6			52	1		5			21	67		3	31	1
	100			*98*	*2*		*100*			*24*	*76*		*8*	*89*	*3*
60–64	12			29	2		23	4		4	74	1	1	75	
	100			*94*	*6*		*85*	*15*		*5*	*94*	*1*	*1*	*99*	
65–69	15	3		47	5	4	32	17			54	5		55	13
	83	*17*		*84*	*9*	*7*	*65*	*35*			*92*	*8*		*81*	*19*
70–74	17	14	2	34	15	16	17	44	2		13	22		13	26
	52	*42*	*6*	*52*	*23*	*25*	*27*	*70*	*3*		*37*	*63*		*33*	*67*
75–79	8	11	11	13	6	59	5	34	7			28			23
	26	*37*	*37*	*17*	*8*	*75*	*11*	*74*	*15*			*100*			*100*
80–84	1	5	7	2	2	25	1	15	33			14			13
	8	*38*	*54*	*7*	*7*	*86*	*2*	*31*	*67*			*100*			*100*
85–89			4			21		1	18			11			13
			100			*100*		*5*	*95*			*100*			*100*
90–94						10			30			8			1
						100			*100*			*100*			*100*

Table VIa.

All voyages arranged in Seasonal Order. Mean lengths in cm., frequencies and mean weights of gonad, liver and flesh in grams, in the 10 cm. categories of males, and of immature, adolescent and mature females, with particulars of the voyages.

Length Category.	Males.					Immature females.					Adolescent females.					Mature females.				
	Frequency. A.	Mean Length. B.	Mean wt. gonad. C.	Mean wt. liver. D.	Mean wt. flesh. E.	Frequency. F.	Mean Length. G.	Mean wt. gonad. H.	Mean wt. liver. J.	Mean wt. flesh. K.	Frequency. L.	Mean Length. M.	Mean wt. gonad. N.	Mean wt. liver. O.	Mean wt. flesh. P.	Frequency. Q.	Mean Length. R.	Mean wt. gonad. S.	Mean wt. liver. T.	Mean wt. flesh. V.
Sir Mark Sykes. St. Kilda. January 13–23, 1926. Mean Depth 186 fathoms. Mean Latitude 57° 40′.																				
50–59	39	55·4	3·87	36·15	950·00	87	54·9	6·17	37·55	921·26										
60–69	51	66·0	11·04	70·84	1641·18	59	64·7	9·32	55·34	1526·27	12	65·9	11·83	78·33	1675·00					
70–79	79	75·0	21·38	115·70	2426·58	27	73·6	16·00	108·96	2375·93	63	75·6	24·41	136·73	2601·59	20	76·6	40·65	144·50	2640·00
80–89	27	84·1	44·70	212·96	3633·33	2	81·5	26·00	125·00	3050·00	22	83·2	37·91	206·36	3518·18	55	85·3	51·05	246·18	3796·36
90–99	4	93·5	50·00	332·50	4800·00											23	94·4	73·57	313·04	5182·61
100–109	1	100·5	190·00	550·00	6200·00											18	104·2	174·44	593·06	7074·44
				Hermaphrodite			77	20	210	3200										
Tamura III. Westward. February 20 to March 1, 1926. Mean Depth 209 fathoms. Mean Latitude 49° 30′.																				
50–59	116	54·9	7·09	33·09	889·66	57	54·7	5·98	23·93	842·11	7	56·9	21·14	64·29	1064·29					
60–69	153	65·3	16·10	57·71	1526·47	67	64·5	9·06	49·57	1453·73	39	65·6	16·49	74·44	1557·69	2	69·5	95·00	105·00	1975·00
70–79	77	74·1	31·91	92·95	2268·83	32	73·2	12·00	65·38	2178·13	36	74·0	32·08	97·08	2212·50	18	76·3	76·28	119·17	2500·00
80–89	19	83·9	89·05	176·57	3515·79	1	81·5	15·00	110·00	3100·00	10	82·1	36·20	148·50	3150·00	52	84·5	81·33	190·10	3528·85
90–99	1	96·5	200·00	290·00	5500·00											41	94·7	118·78	338·05	5119·51
100–109																18	104·0	204·72	536·11	7211·11
110–119																2	113·0	160·00	875·00	10,000·00

Tamura IV. Below Bull. March 20–28, 1926. Mean Depth 166 fathoms. Mean Latitude 52° 30′.

50–59	60	54·8	3·90	24·60	883·33	90	55·5	6·02	24·97	927·33									
60–69	88	65·1	17·90	54·58	1572·16	95	65·2	10·03	41·11	1555·79	10	67·7	20·00	67·50	1760·00	1	69·5	160·00	160·00
70–79	73	74·2	49·71	110·16	2432·88	32	74·0	15·75	80·25	2340·63	64	75·5	31·41	127·31	2573·44	35	77·4	82·57	141·94
80–89	18	83·2	98·56	186·67	3516·67	2	81·0	25·00	135·00	3100·00	20	82·7	45·75	179·50	3345·00	74	84·7	127·86	200·74
90–99																33	94·2	169·55	363·33
100–109																15	103·0	292·67	487·33

Florence Brierley I. Butt of Lewis. March 22 to April 12, 1927. Mean Depth 274 fathoms. Mean Latitude 59° 40′.

50–59	6	55·0	9·17	51·17	1058·33	9	55·1	6·56	41·11	938·89									
60–69	23	64·8	11·09	87·83	1634·78	55	65·1	11·27	88·29	1667·27	21	67·3	16·24	121·95	1876·19				
70–79	17	75·8	46·18	160·88	2605·88	22	73·4	17·73	136·50	2404·55	78	74·9	35·99	184·68	2667·95	9	77·2	58·89	244·44
80–89	10	83·6	118·10	235·00	3590·00	1	80·5	18·00	120·00	3100·00	16	82·0	51·19	241·88	3443·75	51	84·4	78·18	326·08
90–99	2	94·0	275·00	245·00	5050·00											64	95·1	148·67	572·19
100–109	1	100·5	90·00	380·00	5500·00											15	102·6	231·33	632·67

Tamura V. Below Bull. April 18–24, 1926. Mean Depth 150 fathoms. Mean Latitude 52° 30′.

50–59	100	55·3	5·46	23·72	911·50	85	55·0	5·39	22·84	895·88									
60–69	143	64·8	20·20	58·82	1571·68	81	64·2	9·85	41·37	1470·37	11	66·7	23·45	85·00	1759·09	1	66·5	15·00	50·00
70–79	83	74·4	59·94	125·84	2479·52	17	72·4	14·29	60·47	2170·59	54	74·9	62·80	142·87	2605·56	22	76·7	155·82	114·64
80–89	10	82·9	160·50	259·00	3740·00						18	82·7	67·00	192·50	3416·67	41	84·5	209·32	242·56
90–99	1	90·5	260·00	230·00	5300·00											39	94·8	293·08	444·62
100–109																17	105·2	325·29	639·41

Florence Brierley II. Tory Island. April 29 to May 1, 1927. Mean Depth 220 fathoms. Mean Latitude 55° 40′.

50–59	8	57·1	5·38	35·13	1062·50	10	57·4	6·40	45·20	1095·00									
60–69	19	66·5	24·58	93·89	1802·63	19	63·9	9·95	60·84	1515·79	2	67·0	21·00	125·00	1900·00				
70–79	29	75·1	72·38	162·24	2637·93	9	73·2	16·44	113·00	2433·33	32	76·5	45·13	186·53	2856·25	5	75·7	194·00	232·00
80–89	16	83·1	115·69	219·00	3537·50	2	80·5	21·50	120·00	3100·00	14	81·9	68·00	265·71	3521·43	25	84·9	128·80	273·28
90–99	1	90·5	120·00	260·00	3900·00											24	93·7	248·33	390·00
100–109																5	102·7	580·00	534·00

TABLE VIA.—*continued.*

Length Category.	Males.					Immature females.					Adolescent females.					Mature females.				
	Frequency. A.	Mean Length. B.	Mean wt. gonad. C.	Mean wt. liver. D.	Mean wt. flesh. E.	Frequency. F.	Mean Length. G.	Mean wt. gonad. H.	Mean wt. liver. J.	Mean wt. flesh. K.	Frequency. L.	Mean Length. M.	Mean wt. gonad. N.	Mean wt. liver. O.	Mean wt. flesh. P.	Frequency. Q.	Mean Length. R.	Mean wt. gonad. S.	Mean wt. liver. T.	Mean wt. flesh. V.
	Notre-Dame des Dunes.			Westward.		April 28 to May 6, 1928.			Mean Depth 180 fathoms.				Mean Latitude 49° 45′.							
50–59	27	56·3	14	35	1060	78	54·5	6	27	940	3	57·5	9	44	1115					
60–69	108	65·4	31	64	1680	28	63·7	10	51	1495	17	65·4	17	76	1690					
70–79	73	73·1	64	100	2305	1	70·5	25	75	1900	33	75·5	58	140	2580	45	76·9	171	153	2795
80–89	6	82·5	150	175	3235						5	80·9	64	171	3140	85	84·7	225	201	3630
90–99	1	91·5	150	140	4400											28	93·6	330	280	4925
100–109																5	102·1	592	370	6940
110–119																1	110·5	630	650	8800
	Florence Brierley II.			St. Kilda.		May 1 to May 9, 1927.			Mean Depth 316 fathoms.				Mean Latitude 58° 00′.							
50–59																				
60–69	17	65·6	12·18	96·35	1723·53	22	66·8	10·55	108·86	1897·73	2	69·0	17·00	120·00	2200·00					
70–79	23	74·9	33·70	161·52	2582·61	15	72·3	14·47	138·53	2346·67	63	75·7	32·33	197·00	2811·11	3	78·2	133·33	290·00	3333·33
80–89	8	83·1	116·00	223·75	3562·50	2	81·0	24·50	220·00	3450·00	17	82·8	50·41	270·29	3717·65	42	86·1	128·69	348·57	4223·81
90–99											1	93·5	18·00	340·00	5300·00	39	92·8	191·64	467·31	5212·82
100–109																14	103·3	320·00	689·29	7357·14
	Tamura VI.	Below Bull.				May 29 to June 5, 1926.			Mean Depth 114 fathoms.				Mean Latitude 52° 30′.							
50–59	87	55·0	2·89	19·79	931·61	98	55·8	6·06	19·79	952·55										
60–69	93	64·5	13·29	45·49	1531·72	160	65·0	10·19	38·16	1554·69	13	68·0	32·54	90·38	1930·77					
70–79	46	74·0	52·72	102·28	2421·74	80	73·8	14·86	62·23	2312·50	114	75·2	40·25	120·53	2594·74	43	77·3	178·95	168·37	2890·70
80–89	6	85·5	86·17	145·83	3866·67	5	82·3	21·00	80·00	3200·00	24	82·5	49·96	137·92	3420·83	75	84·3	187·20	221·75	3770·67
90–99																27	94·4	345·74	346·67	5462·96
100–109																15	103·6	528·00	460·00	7380·00

Tamura VII. Below Bull. June 12–19, 1926. Mean Depth 107 fathoms. Mean Latitude 52° 30′.

50–59	123	55·4	1·89	18·41	903·66	87	55·7	4·78	17·68	927·59									
60–69	124	64·1	9·93	41·45	1459·27	164	65·3	9·62	37·92	1542·07	23	68·2	22·87	75·04	1891·30				
70–79	51	73·6	53·33	75·49	2307·84	69	74·2	15·28	61·75	2308·70	142	75·5	63·18	116·74	2584·86	26	77·7	209·04	169·23	2851·[illegible]
80–89	9	83·2	88·78	128·89	3522·22	3	82·8	27·67	106·67	3133·33	28	82·1	64·50	140·54	3335·71	90	84·3	236·06	201·56	3717·[illegible]
90–99											1	96·5	45·00	160·00	4700·00	24	93·6	394·38	322·92	5212·[illegible]
100–109																7	103·4	597·14	391·43	6757·[illegible]

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Iolite. Norwegian Deep. June 21–24, 1928. Mean Depth 114 fathoms.

50–59	15	55·4	20	40	1035	68	53·6	8	32	940	132	55·1	10	41·	1045				
60–69	20	63·8	45	76	1605	4	61·5	10	40	1300	128	64·6	30	82	1670	6	68·3	97	123	2065
70–79	5	75·3	100	150	2780						13	71·7	54	160	2360	50	75·3	155	189	2880
80–89	2	80·5	44	170	3550											25	84·5	225	334	4210
90–99																16	94·6	377	571	6205
100–109																2	105·0	370	725	7800

Iolite. Skagerrak. June 25–29, 1928. Mean Depth 122 fathoms.

50–59	58	54·9	28	44	1070	12	53·4	10	32	940	59	55·2	14	44	1065	1	59·5	15	100	1400
60–69	60	63·6	58	85	1645	1	60·5	10	40	1300	130	64·5	44	97	1730	13	68·0	115	138	2115
70–79	18	74·2	153	159	2665						13	71·4	73	146	2360	49	74·6	175	211	2865
80–89																26	84·2	264	348	4235
90–99																4	95·8	378	578	6300
100–109																4	105·5	523	825	8775

Tamura VIII. Below Bull. July 9–17, 1926. Mean Depth 116 fathoms. Mean Latitude 52° 30′.

50–59	136	55·5	2·76	21·36	940·07	112	55·4	5·54	19·73	945·54									
60–69	142	65·0	8·87	40·88	1532·04	131	65·2	9·68	35·96	1532·06	9	67·5	23·78	62·44	1811·11				
70–79	61	73·8	42·16	64·70	2243·44	72	73·7	16·04	61·18	2256·25	103	75·4	35·05	110·03	2500·00	33	77·1	153·55	113·36	2672·73
80–89	6	82·7	70·83	87·67	3300·00	4	83·0	23·25	136·25	3475·00	24	82·9	49·04	135·21	3257·17	55	84·0	181·02	173·27	3469·09
90–99																25	93·6	258·60	232·80	4864·00
100–109																5	103·1	303·20	276·00	6780·00

TABLE VIA.—*continued.*

Length Category.	Males. Frequency. A.	Males. Mean Length. B.	Males. Mean wt. gonad. C.	Males. Mean wt. liver. D.	Males. Mean wt. flesh. E.	Immature females. Frequency. F.	Immature females. Mean Length. G.	Immature females. Mean wt. gonad. H.	Immature females. Mean wt. liver. J.	Immature females. Mean wt. flesh. K.	Adolescent females. Frequency. L.	Adolescent females. Mean Length. M.	Adolescent females. Mean wt. gonad. N.	Adolescent females. Mean wt. liver. O.	Adolescent females. Mean wt. flesh. P.	Mature females. Frequency. Q.	Mature females. Mean Length. R.	Mature females. Mean wt. gonad. S.	Mature females. Mean wt. liver. T.	Mature females. Mean wt. flesh. V.
Västerhavet. Firth of Clyde. July 15–18, 1929. Mean Depth 30 fathoms.																				
50–59	56	54·8	17	30	945	6	54·8	7	30	975						1	55·5	140	52	1000
60–69	66	64·6	43	43	1555						8	64·8	71	59	1565	39	67·3	155	75	1740
70–79	39	73·6	81	61	2270											110	75·2	245	91	2385
80–89	4	82·3	161	90	3140											70	84·2	435	147	3370
90–99																23	94·2	528	237	4665
George Bligh. Below Bull. August 27–29, 1928. Mean Depth 135 fathoms. Mean Latitude 52° 30′.																				
50–59	81	55·8	4	26	990	55	54·6	5	24	925										
60–69	94	64·2	10	46	1495	37	64·3	10	37	1470	5	67·1	22	56	1710	4	67·0	51	70	1675
70–79	41	73·1	17	72	2155	9	73·6	13	56	2170	5	75·7	49	93	2460	61	75·2	54	98	2470
80–89	5	82·9	38	103	3060											29	84·2	93	126	3340
90–99																4	92·5	92	158	4375
100–109																2	105·0	83	350	7550
Florence Brierley III. St. Kilda. September 7–8, 1927. Mean Depth 168 fathoms. Mean Latitude 58° 00′.																				
50–59	8	56·8	2	35	965	11	55·6	7	27	950										
60–69	26	66·0	6	59	1655	27	65·5	10	49	1590	3	68·5	20	94	1965					
70–79	34	74·2	20	83	2310	25	73·7	17	76	2290	25	74·8	29	118	2475	13	77·6	33	102	2590
80–89	6	83·2	31	92	3135	1	81·5	20	110	2900	5	81·1	40	172	3220	11	83·7	54	154	3510
90–99																3	92·2	69	173	4765

Florence Brierley III. Tory Island. September 11–12, 1927. Mean Depth 112 fathoms. Mean Latitude 55° 40′.

50–59	22	55·4	4	29	930	39	55·6	7	26	925						1	69·5	140	250	2[illegible]
60–69	27	64·9	7	46i	1475	45	65·3	11	47	1520	1	65·5	20	90	1600	6	77·3	125	171	2[illegible]
70–79	13	75·1	25	86	2310	13	73·3	16	70	2130	16	76·3	67	119	2530	13	85·5	157	174	3[illegible]
80–89	5	82·5	64	119	2980	1	81·5	26	58	2800	1	83·5	27	70	3200	15	94·4	144	227	4[illegible]
90–99	1	97·5	140	160	4900											3	103·8	143	387	6700
100–109																1	111·5	210	190	8200
110–119																				

Florence Brierley III. Donegal Bay. September 13, 1927. Mean Depth 42 fathoms.

50–59	93	54·2	8	20	810	15	54·1	6	29	850	3	56·2	45	41	970	2	57·5	110	33	9[illegible]
60–69	21	62·8	25	37	1230	2	62·5	10	41	1300	3	62·2	42	105	1370	2	65·5	69	66	1[illegible]
70–79	9	74·1	41	68	2120						3	72·8	141	98	2000	1	75·5	28	130	2[illegible]
80–89																				
90–99																3	92·8	450	200	4300

Tamura I. Below Bull. September 19–23, 1925. Mean Depth 147 fathoms. Mean Latitude 52° 30′.

50–59	16	57·4		29		28	55·4		21	
60–69	22	65·7		43		53	64·8		38	
70–79	8	74·4		72	Not distinguished into Immatures,	27	74·1		69	
80–89	3	81·5		157	Adolescents and Matures.	13	82·9	54·4	122	
90–99						9	92·2	62·5	212	
100–109						2	101·0		375	

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Tamura I. Galway Bay. September 24–27, 1925. Mean Depth 56 fathoms.

50–59	21	55·6		62		39	55·1		70	
60–69	18	64·7		73		38	65·2		94	
70–79	17	74·1		71	Not distinguished into Immatures,	54	75·2		109	
80–89	1	85·5		140	Adolescents and Matures.	36	84·2	154	143	
90–99						6	93·3	162	183	
100–109						2	104·0		205	

TABLE VIA.—*continued.*

Length Category.	Males.					Immature females.					Adolescent females.					Mature females.				
	Frequency. A.	Mean Length. B.	Mean wt. gonad. C.	Mean wt. liver. D.	Mean wt. flesh. E.	Frequency. F.	Mean Length. G.	Mean wt. gonad. H.	Mean wt. liver. J.	Mean wt. flesh. K.	Frequency. L.	Mean Length. M.	Mean wt. gonad. N.	Mean wt. liver. O.	Mean wt. flesh. P.	Frequency. Q.	Mean Length. R.	Mean wt. gonad. S.	Mean wt. liver. T.	Mean wt. flesh. V.
	Tamura IX. Porcupine Bank and below Bull. October 15–26, 1926. Mean Depth 154 fathoms. Mean Latitude 52° 30′.																			
50–59	64	55·5	2·42	28·05	961·72	111	55·8	5·69	28·18	985·14										
60–69	61	64·5	4·56	47·54	1536·07	168	64·9	8·56	44·01	1566·67	3	65·5	12·67	42·67	1666·67					
70–79	23	73·8	8·30	68·13	2267·39	54	73·9	13·63	70·78	2340·74	22	74·3	16·77	87·05	2390·91	2	74·5	19·00	91·00	2400·00
80–89	3	84·8	13·00	101·33	3433·33	4	85·0	23·25	70·50	3500·00	6	82·8	24·33	125·83	3333·33	9	83·5	27·78	130·00	3244·44
90–99																3	94·2	50·33	206·67	4900·00
	Kumu. St. Kilda and Flannan Islands. October 17–26, 1928. Mean Depth 129 fathoms. Mean Latitude 58° 30′.																			
50–59	31	55·1	3	42	980	71	56·3	5	41	1010	1	57·5	20	40	1050					
60–69	66	65·4	6	64	1585	76	65·6	9	58	1620	7	66·5	13	79	1730	4	68·5	13	76	1975
70–79	35	73·4	11	82	2195	47	73·2	13	79	2205	21	73·8	22	133	2360	75	76·4	23	124	2585
80–89	7	83·5	22	109	3255	2	81·0	18	125	3100	2	82·5	35	270	3450	46	84·6	36	168	3465
90–99																16	94·0	75	258	4765
100–109																6	102·8	116	305	6135
	Alida. Donegal Bay. October 31 to November 6, 1925. Mean Depth 46 fathoms.																			
50–59	76	55·3	4	41	1030	Not distinguished into Immatures, Adolescents and Matures.					130	55·9	6	44	1065					
60–69	82	65·4	13	58	1605						113	64·5	14	75	1590					
70–79	83	73·5	25	74	2205						61	75·2	70	120	2455					
80–89	5	82·3	48	94	3130						21	84·2	96	161	3355					
90–99											2	92·0	95	195	4325					

	Tamura II.		Below Bull.			November 28 to December 3, 1925.					Mean Depth 179 fathoms.					Mean Latitude 52° 30′.				
50–59	64	56·2	2·88	37·94	946·88	83	55·9	5·52	36·95	933·13	4	57·5	8·25	70·00	1075·00					
60–69	89	64·4	4·25	55·15	1465·73	80	64·5	8·79	62·38	1470·00	12	66·0	13·25	79·42	1600·00					
70–79	30	72·8	12·13	86·97	2141·67	27	74·0	15·56	78·26	2222·22	30	75·1	25·50	139·33	2548·33					
80–89	3	82·2	24·33	140·00	3366·67	4	81·5	19·00	122·50	3150·00	9	81·8	32·22	136·67	3033·33	9	85·1	48·44	192·22	3466·67
90–99											1	93·5	50·00	110·00	4900·00	9	95·5	93·33	323·33	5144·44
100–109																2	104·0	102·50	470·00	6850·00

Table VIb.

The data, arranged as in Table VIa, obtained at the Stations worked by the Research Vessel "George Bligh," in August, 1928, except those applying to the Bull Ground, which are given in Table VIa.

						Bantry Bay.					30 fathoms.									
50–59	17	52·6	10	34	850	8	53·4	7	33	895	1	57·5	60	55	1050					
60–69	1	60·5	22	44	1300	1	61·5	10	65	1300	3	64·2	57	100	1550	5	67·7	128	101	1770
70–79																14	74·9	166	132	2385
80–89																6	84·0	181	172	3550
90–99																1	91·5	230	430	4800
						Minehead.					37 fathoms.									
50–59	34	53·7	14	33	885						5	54·5	18	76	1030					
60–69	8	62·9	30	46	1420											2	68·0	143	120	1800
70–79	1	74·5	10	47	2200											4	74·0	143	96	2225
80–89																1	85·5	240	160	3600
						Galway Bay.					55 fathoms.									
50–59	47	54·4	7	17	895	34	54·0	6	24	895	14	56·2	26	43	1015					
60–69	34	65·5	15	39	1480	13	63·7	11	35	1340	18	65·0	37	68	1500	5	67·3	81	59	1590
70–79	8	74·4	36	53	2125						2	72·0	44	88	2000	24	75·9	106	93	2395
80–89	2	85·0	35	59	3300											27	85·4	162	121	3320
90–99																12	93·8	212	174	4240

TABLE VIB.—*continued.*

Length Category.	Males.					Immature females.					Adolescent females.					Mature females.				
	Frequency. A.	Mean Length. B.	Mean wt. gonad. C.	Mean wt. liver. D.	Mean wt. flesh. E.	Frequency. F.	Mean Length. G.	Mean wt. gonad. H.	Mean wt. liver. J.	Mean wt. flesh. K.	Frequency. L.	Mean Length. M.	Mean wt. gonad. N.	Mean wt. liver. O.	Mean wt. flesh. P.	Frequency. Q.	Mean Length. R.	Mean wt. gonad. S.	Mean wt. liver. T.	Mean wt. flesh. V.
Galley Head. 61 fathoms.																				
50–59	39	53·9	10	37	900	16	53·4	7	51	925	11	56·0	37	70	1070					
60–69	21	65·1	18	81	1620						3	63·5	59	94	1450	3	67·5	59	112	1965
70–79	8	73·5	31	79	2195						1	72·5	105	100	2300	16	76·8	135	146	2565
80–89	1	86·5	42	70	3200											19	84·7	155	190	3435
90–99																8	93·1	238	228	4475
100–109																3	102·8	243	210	5735
Between the Banks. 69 fathoms.																				
50–59	14	54·4	5	23	895	35	53·7	7	34	905	8	55·9	23	67	1080					
60–69	11	63·6	11	55	1470	3	61·5	9	54	1400	5	62·5	28	100	1500					
70–79	3	72·8	26	53	2035											2	78·5	53	60	2750
80–89	1	80·5	55	70	3000											1	82·5	42	160	3200
90–99																1	98·5	120	120	5200
100–109																4	104·5	420	258	6675
Cockburn Bank. 81 fathoms.																				
50–59	9	55·8	5	34	965	13	54·7	6	20	920	1	59·5	12	38	1100					
60–69	18	65·2	9	45	1610	19	64·4	10	50	1505	5	63·9	18	76	1480	5	67·5	15	100	1940
70–79	10	74·3	20	69	2330	3	74·5	12	33	2300	3	73·2	21	105	2335	22	76·0	44	114	2610
80–89											1	80·5	37	200	3200	24	84·0	73	157	3415
90–99	1	93·5	50	65	4000											5	97·1	164	250	5280
100–109																6	106·5	203	302	6965

Eastward. 92 fathoms.

50–59	1	56·5	5	28	1150	11	52·5	5	25	790	1	59·5	10	100	1250					
60–69	14	64·7	18	57	1515	7	64·8	10	28	1430										
70–79	12	74·0	20	84	2205	3	74·5	15	63	2285	1	77·5	40	150	2800	11	75·4	67	91	2470
80–89	1	84·5	20	190	3400											16	84·0	156	126	3330
90–99																14	96·1	152	244	5170
100–109																5	102·9	192	277	6320

Westward. 132 fathoms.

50–59	20	55·9	3	29	1005	26	54·9	6	27	980										
60–69	59	65·6	12	42	1585	17	63·4	10	44	1470	4	66·5	18	63	1700					
70–79	32	72·9	20	58	2165	2	71·0	9	45	1950	1	71·5	15	105	2100	11	75·3	57	104	2485
80–89	4	84·3	61	138	3600											22	84·4	61	158	3510
90–99																8	95·5	129	219	4940
100–109																6	103·7	182	287	6265

Hermaphrodite	58	—	10	100	1200

Table VII.

The values of the coefficient "K," at the time of Minimum and Maximum Mean weight, of the organs of the four biological sub-classes of hake.

Calculated from Table VIa.

Mature Males.

Length Category.	Testis.			Liver.			Flesh.		
	Value of "K" (testis) at min.	max.	diff.	Value of "K" (liver) at min.	max.	diff.	Value of "K" (flesh) at min.	max.	diff.
50–59	·0014	·0032	·0018	·012	·014	·002	—	—	—
60–69	·0017	·0074	·0057	·015	·022	·007	·555	·578	·023
70–79	·0021	·0145	·0124	·016	·030	·014	·555	·602	·047
80–89	·0021	·0282	·0261	·016	·045	·029	·537	·619	·082

Mature Females.

Length Category.	Ovary.			Liver.			Flesh.		
	Value of "K" (ovary) at min.	max.	diff.	Value of "K" (liver) at min.	max.	diff.	Value of "K" (flesh) at min.	max.	diff.
70–79	·0046	·0446	·0400	·0170	·0364	·0194	·581	·629	·048
80–89	·0047	·0394	·0347	·0214	·0402	·0188	·557	·646	·089
90–99	·0060	·0481	·0421	·0200	·0522	·0322	·553	·663	·110
100–109	·0091	·0540	·0449	·0252	·0549	·0297	·611	·668	·057

Adolescent Females.

Length Category.	Ovary.			Liver.			Flesh.		
	Value of "K" (ovary) at min.	max.	diff.	Value of "K" (liver) at min.	max.	diff.	Value of "K" (flesh) at min.	max.	diff.
60–69	·0045	·0103	·0058	·0152	·0287	·0135	·557	·615	·058
70–79	·0041	·0150	·0109	·0212	·0340	·0128	·578	·620	·042
80–89	·0043	·0118	·0075	·0221	·0340	·0119	·555	·609	·054

Immature Females.

Length Category.	Ovary.	Liver.			Flesh.		
		Value of "K" (liver) at min.	max.	diff.	Value of "K" (flesh) at min.	max.	diff.
50–59	No significant variation ...	·0102	·0146	·0044	—	—	—
60–69		·0130	·0156	·0026	—	—	—
70–79		·0140	·0198	·0058	—	—	—

TABLE VIII.

Bull Grounds. Fundamental metabolism of Mature male and female hake compared.

The increase in weight of gonad, and of liver and flesh combined, over the minimum are calculated as a percentage of the total seasonal variation in weight. Males of 70-79 cms., females 80-89 cms.

Data from Table VIA.

Females. Roe. Maximum mean weight, June, 236·06 gms.; minimum mean weight, October, 27·78 gms. Seasonal variation = 208·28 gms.

Liver and flesh. Maximum mean weight, April, 4135·24 gms.; minimum mean weight, October, 3374·44 gms. Seasonal variation = 760·80 gms.

Males. Testis. Maximum mean weight, April, 59·94 gms.; minimum mean weight, October, 8·30 gms. Seasonal variation = 51·64 gms.

Liver and flesh. Maximum mean weight, April, 2605·36 gms.; minimum mean weight, August, 2227 gms. Seasonal variation = 378·36 gms.

Month.	Males 70·79 cms.		Females 80·89 cms.	
	Percentage Testis.	Liver and flesh.	Ovary.	Liver and flesh.
March	$\frac{(49{\cdot}71-8{\cdot}30)\times 100}{51{\cdot}64} = 80{\cdot}2$ Per cent.	$\frac{(2543{\cdot}04-2227)\times 100}{378{\cdot}36} = 83{\cdot}5$ Per cent.	$\frac{(127{\cdot}86-27{\cdot}78)\times 100}{208{\cdot}28} = 48{\cdot}1$ Per cent.	$\frac{(3862{\cdot}90-3374{\cdot}44)\times 100}{760{\cdot}80} = 64{\cdot}2$ Per cent.
April	$\frac{(59{\cdot}94-8{\cdot}30)\times 100}{51{\cdot}64} = 100$	$\frac{(2605{\cdot}36-2227)\times 100}{378{\cdot}36} = 100$	$\frac{(209{\cdot}32-27{\cdot}78)\times 100}{208{\cdot}28} = 87{\cdot}2$	$\frac{(4135{\cdot}24-3374{\cdot}44)\times 100}{760{\cdot}80} = 100{\cdot}0$
May-June ...	$\frac{(52{\cdot}72-8{\cdot}30)\times 100}{51{\cdot}64} = 86{\cdot}0$	$\frac{(2524{\cdot}02-2227)\times 100}{378{\cdot}36} = 78{\cdot}5$	$\frac{(187{\cdot}20-27{\cdot}78)\times 100}{208{\cdot}28} = 76{\cdot}5$	$\frac{(3992{\cdot}42-3374{\cdot}44)\times 100}{760{\cdot}80} = 81{\cdot}2$
June	$\frac{(53{\cdot}33-8{\cdot}30)\times 100}{51{\cdot}64} = 87{\cdot}2$	$\frac{(2383{\cdot}33-2227)\times 100}{378{\cdot}36} = 41{\cdot}3$	$\frac{(236{\cdot}06-27{\cdot}78)\times 100}{208{\cdot}28} = 100{\cdot}0$	$\frac{(3929{\cdot}34-3374{\cdot}44)\times 100}{760{\cdot}80} = 71{\cdot}6$
July	$\frac{(42{\cdot}16-8{\cdot}30)\times 100}{51{\cdot}64} = 65{\cdot}6$	$\frac{(2308{\cdot}14-2227)\times 100}{378{\cdot}36} = 21{\cdot}4$	$\frac{(181{\cdot}02-27{\cdot}78)\times 100}{208{\cdot}28} = 73{\cdot}6$	$\frac{(3642{\cdot}36-3374{\cdot}44)\times 100}{760{\cdot}80} = 35{\cdot}2$
August	$\frac{(17{\cdot}00-8{\cdot}30)\times 100}{51{\cdot}64} = 16{\cdot}8$	$\frac{(2227-2227)\times 100}{378{\cdot}36} = 0{\cdot}0$	$\frac{(93{\cdot}00-27{\cdot}78)\times 100}{208{\cdot}28} = 31{\cdot}3$	$\frac{(3466{\cdot}00-3374{\cdot}44)\times 100}{760{\cdot}80} = 12{\cdot}0$
October ...	$\frac{(8{\cdot}30-8{\cdot}30)\times 100}{51{\cdot}64} = 0{\cdot}0$	$\frac{(2335{\cdot}52-2227)\times 100}{378{\cdot}36} = 28{\cdot}7$	$\frac{(27{\cdot}78-27{\cdot}78)\times 100}{208{\cdot}28} = 0{\cdot}0$	$\frac{(3374{\cdot}44-3374{\cdot}44)\times 100}{760{\cdot}80} = 0{\cdot}0$
Nov.-Dec. ...	$\frac{(12{\cdot}13-8{\cdot}30)\times 100}{51{\cdot}64} = 7{\cdot}4$	$\frac{(2228{\cdot}64-2227)\times 100}{378{\cdot}36} = 0{\cdot}4$	$\frac{(48{\cdot}44-27{\cdot}78)\times 100}{208{\cdot}28} = 9{\cdot}9$	$\frac{(3658{\cdot}89-3374{\cdot}44)\times 100}{760{\cdot}80} = 37{\cdot}4$

Table IXa.

Monthly Landings (in cwts.) of Big and Medium Hake (column 1), Livers (column 2) and Roes (column 3) at Cardiff, 1921–9
Data from Ministry of Agriculture and Fisheries Monthly Returns of Sea-Fisheries.

	1921.			1922.			1923.			1924.			1925.			1926.			1927.			1928.			Means (1923–8).			1929.		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Jan. ...	1,991	42	3	2,093	32	3	2,448	40	6	3,296	44	—	3,848	44	—	4,777	32	—	3,442	48	—	3,220	48	—	3,505	42·7	1·0	3,444	(46)	4
Feb. ...	2,439	88	11	1,862	26	7	2,484	54	38	3,140	46	39	3,170	26	2	3,967	28	—	3,058	64	10	2,905	54	22	3,121	45·3	18·5	2,283	18	25
Mar. ...	3,283	56	79	2,376	24	114	3,190	50	90	2,015	32	57	2,899	52	48	4,317	34	38	3,978	72	32	3,398	46	47	3,300	47·7	52·0	2,545	—	71
Apr. ...	3,779	—	82	2,880	21	72	5,293	17	166	5,108	48	156	4,614	54	74	4,922	24	47	5,454	52	31	5,045	24	49	5,073	36·5	87·2	5,597	—	40
May ...	4,870	—	117	6,350	12	184	7,167	—	321	9,988	12	296	7,657	2	175	7,370	—	135	7,643	—	128	6,450	—	60	7,713	2·3	185·8	5,139	—	83
June ...	8,256	—	332	7,466	—	240	8,648	—	437	9,935	—	393	8,206	—	105	7,774	—	103	7,583	—	30	6,164	—	67	8,052	—	189·2	3,944	—	66
July ...	8,454	—	241	4,776	—	94	9,171	—	401	6,254	—	219	7,307	—	146	8,184	—	76	7,309	—	6	7,039	—	30	7,544	—	146·3	3,674	—	32
Aug. ...	7,627	—	76	4,921	—	30	6,070	—	69	4,776	—	45	5,558	—	25	5,705	—	39	5,973	—	6	6,596	—	1	5,780	—	30·8	3,406	—	20
Sept. ...				3,369	14	—	3,941	—	14	3,826	—	—	3,777	14	12	5,301	—	—	5,660	—	—	4,299	8	—	4,467	3·7	4·3	2,693	—	1
Oct. ...	2,872	29	—	2,198	51	—	4,024	25	—	5,810	44	—	4,871	54	2	4,031	4	—	3,645	14	—	3,484	40	1	4,311	30·2	0·5	2,546	—	—
Nov. ...	1,966	55	—	1,770	46	—	2,778	52	—	3,363	52	—	3,358	58	—	2,685	26	—	3,871	64	—	3,148	48	—	3,201	50·0	—	2,290	—	—
Dec. ...	1,573	40	2	2,082	46	—	3,828	42	2	3,345	59	—	4,389	70	—	4,330	36	—	2,201	56	—	2,428	26	—	3,420	48·2	0·3	1,832	10	—

Table IXb.

Monthly Landings of Big and Medium Hake (all ports) and price per cwt. 1927–8.
Data from the Ministry's Monthly Returns of Sea Fisheries.

Month. 1927.	Big and Medium Hake. cwts.	Price per cwt.	Month 1927.	Big and Medium Hake. cwts.	Price per cwt.	Month 1928.	Big and Medium Hake. cwts.	Price per cwt.	Month 1928.	Big and Medium Hake. cwts.	Price per cwt.
		£			£			£			£
January ...	17,685	3·2	July ...	55,025	1·5	January ...	10,462	4·1	July ...	45,691	2·0
February ...	16,389	3·0	August ...	48,805	2·1	February ...	9,688	4·1	August ...	39,885	2·4
March ...	30,630	2·4	September ...	32,742	2·6	March ...	27,851	2·5	September ...	25,336	2·8
April	34,425	2·6	October ...	20,400	3·3	April ...	29,607	2·9	October ...	22·147	3·3
May	45,230	2·0	November ...	16,683	3·6	May ...	42,515	2·2	November ...	14,265	3·8
June	50,760	1·8	December ...	11,178	3·7	June ...	39,576	2·2	December ...	14,542	3·4

Table X

Dispersion of Weights of adolescent and mature hake roes in six samples from the Bull grounds, 70–89 cms.

Frequency in upright, percentage frequency in italic numerals.

Weight.	March.		April.		May-June.		June.		July.		Nov.-Dec.	
gms.												
1–50	120	*62*	50	*37*	116	*45*	117	*41*	117	*54*	45	*94*
51–100	36	*18*	31	*23*	40	*16*	32	*11*	30	*14*	3	*6*
101–150	11	*6*	17	*13*	31	*12*	35	*12*	24	*11*		
151–200	8	*4*	10	*7*	22	*9*	33	*12*	13	*6*		
201–250	10	*5*	8	*6*	19	*7*	27	*9*	15	*7*		
251–300	3	*1*	6	*4*	14	*5*	17	*6*	5	*2*		
301–350			5	*4*	7	*3*	7	*3*	6	*3*		
351–400	2	*1*	6	*4*	2	*1*	8	*3*	4	*2*		
401–450			1	*1*	4	*2*	5	*2*				
451–500	1	*1*	1	*1*			2	*1*	1	*1*		
501–550	1	*1*					1	*0*				
551–600							1	*0*				
601–650					1	*0*						
651–700	1	*1*										
701–750												
751–800												
801–850							1	*0*				
Total ...	193		135		256		286		215		48	

Table XI.

Values of k (liver) and k (flesh) in the Butt of Lewis (April) and Skagerrak (June) samples compared with those in the nearest Bull sample in point of time.

Calculated from Table VIa.

	Bull (April).		Butt of Lewis (April).				Bull (June).		Skagerrak (June).			
	k (liver).	k (flesh).	k (liver).	Per cent. of Bull value	k (flesh).	Per cent. of Bull value	k (liver).	k (flesh).	k (liver).	Per cent. of Bull value	k (flesh).	Per cent. of Bull value
Males.												
50–59	·0140	·539	·0308	*220*	·636	*118*	·0108	·531	·0266	*246*	·647	*122*
60–69	·0216	·578	·0323	*150*	·601	*104*	·0157	·554	·0330	*210*	·639	*115*
70–79	·0306	·602	·0369	*121*	·598	*99*	·0189	·579	·0389	*206*	·652	*113*
80–89	·0455	·656	·0402	*88*	·614	*94*						
Females.												
Immature												
50–59	·0137	·539	·0246	*180*	·561	*104*	·0102	·537	·0210	*206*	·617	*115*
60–69	·0156	·555	·0320	*205*	·604	*109*	·0136	·554	·0181	*133*	·587	*106*
70–79	·0159	·573	·0345	*217*	·608	*106*						
Adolescent												
60–69	·0286	·593	·0400	*140*	·615	*104*	·0237	·596	·0361	*152*	·645	*108*
70–79	·0340	·620	·0440	*129*	·635	*102*	·0271	·601	·0401	*148*	·648	*108*
80–89	·0340	·604	·0439	*129*	·625	*103*						
Mature												
70–79	·0254	·590	·0531	*209*	·638	*108*	·0361	·629	·0508	*141*	·690	*110*
80–89	·0402	·645	·0542	*135*	·652	*101*	·0336	·621	·0583	*174*	·709	*114*
90–99	·0522	·663	·0665	*127*	·681	*103*	·0394	·636	·0657	*167*	·717	*113*
100–109	·0549	·667	·0583	*107*	·656	*98*	·0354	·611	·0703	*199*	·747	*122*
			Mean	*154*		*104*			Mean	*180*		*113*

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